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Land management decisions need to balance the social, political, economic, ecological goals for the use of land. Often, however, the ecological goals for the land are not clearly stated, nor are the means of obtaining these goals specified. Therefore, this project has developed an approach for establishing ecological goals through the use of procedures to use ecological models that support land-use decisions: these models show how ecological goals for land use and management can be established and met. This approach is designed to be incorporated into a decision process that includes the other three goals for land use and management.

This report describes the ecological models that were developed under SERDP project 758-62, Ecological Modeling in Support of Military Land-Use Decisions. First, the general approach is set forth, and then example models and their applications are described.

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Final Report of SERDP Project CS 758
December 23, 1998

Spatially Explicit Ecological Models for Land-Use Decisions: Examples for Military Land Management

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DoD EPA DOE SERDP
Strategic Environmental Research and Development Program

Improving Mission Readiness Through Environmental Research

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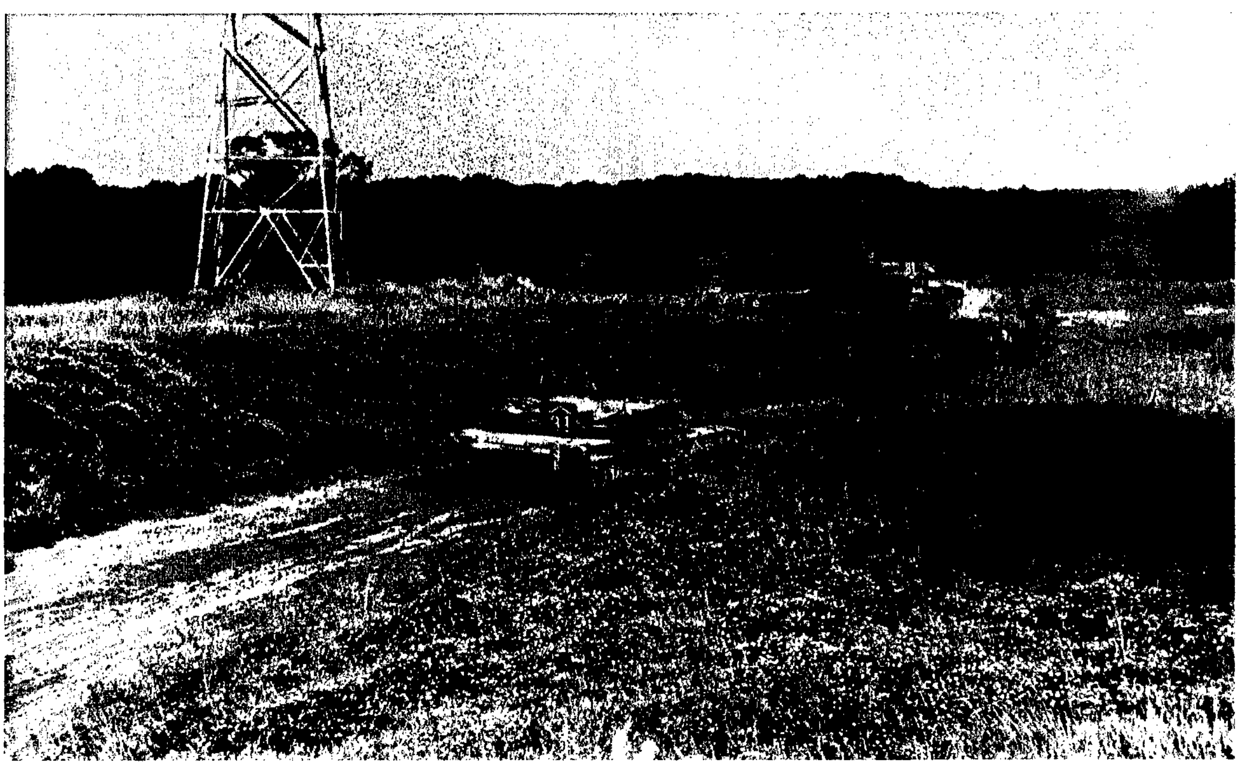
INTRODUCTION

Land management decisions need to balance the social, political, economic, ecological goals for the use of land. Often, however, the ecological goals for the land are not clearly stated, nor are the means of obtaining these goals specified. Therefore, this project has developed an approach for establishing ecological goals through the use of procedures to use ecological models that support land-use decisions: these models show how ecological goals for land use and management can be established and also met. This approach is designed to be incorporated into a decision process that includes the other three goals for land use and management.

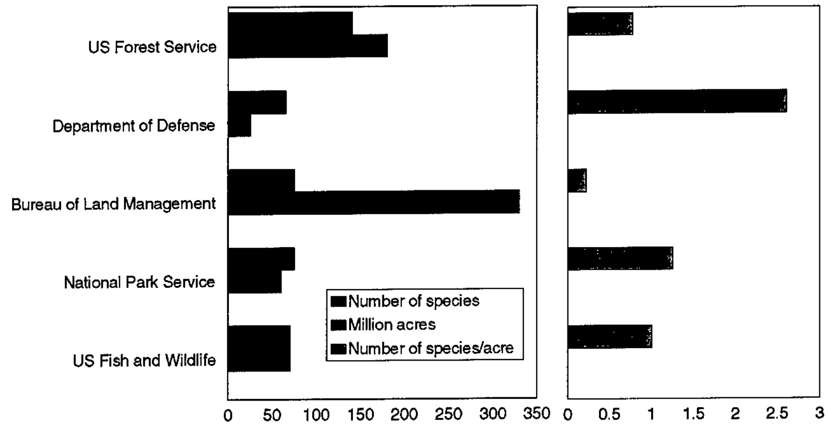
The examples of spatially explicit ecological models developed by the project deal with land-use decisions typically made by the U.S. Department of Defense (DoD) on their installations. DoD must meet its mission needs while at the same time conserving ecological resources; however, DoD missions frequently require training or testing on land areas that may jeopardize these resources (Dale at al. 1996). The Endangered Species Act (ESA) requires that federal land actions protect threatened and endangered species, and the National Environmental Protection Act (NEPA), the Clean Water Act, and the Clean Air Act requires protection of environmental resources. These two federal regulations are the primary regulatory devices that are designed to conserve natural resources. Thus, military training and testing must conserve natural resources protected by such federal regulations.

Tank training at Fort Knox, Kentucky.



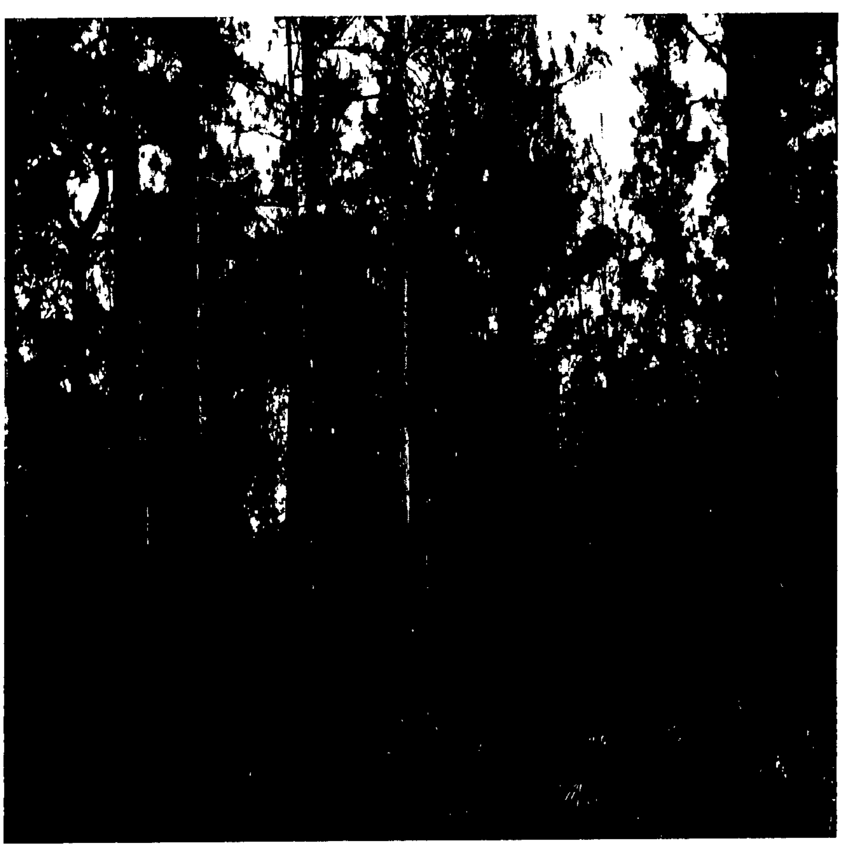
The conservation task is not a minor one. Because the DoD lands have been largely protected from development and other disturbances and because large areas were set aside to buffer military missions, the DoD lands now contain as many as 80% of the threatened and endangered species that are found on all federal lands (Leslie et al. 1996).

Occurrence of endangered species by land ownership (from Leslie et al. 1996)



As habitat for these species or other natural resources are reduced on private and other federal lands, there is mounting pressure for DoD to manage their lands in such a way as to protect these threatened and endangered species and resources. DoD is addressing this challenge to protect these features with the active participation of the installations. Yet, a site-by-site approach to conservation is not enough. The Strategic Environmental Research and Development Program (SERDP) has taken on the task of providing funding to develop tools needed for the protection of natural reserves on the DoD installations. Ecological models are one of the promising tools.

Ecological models can explore ways that missions can be conducted with minimal impact on natural resources. They can also evaluate the types and sensitivity of ecosystems and organisms at risk. They can help determine whether, under certain temporal or spatial restraints, missions may be conducted in such a way that resources are not put at risk. The advantage of using ecological models is that both mission goals and ecological risks can be explored without jeopardizing either of these objectives.



The purpose of this report is to illustrate how we developed and applied ecological models that can provide land managers with information about the impacts that land use and management activities have on natural resources.

The long leaf pine/wire grass community required by the endangered red cockaded woodpecker.

A variety of land management issues face DOD. Installations must manage natural resources within their site. Often, however, management of natural resources across installations is of concern. Land managers must identify and locate critical habitats. The training and land management groups must predict the result of training and land management actions. Moreover, monitoring activities must be focused in such a way to obtain the necessary information required for effective management with minimal cost.

Military land uses provide challenges to traditional ecological modeling. First, military training or testing typically occurs in intensive spurts, with only a short time (a few years or months) between uses. Therefore, ecological models that typically run for decades or centuries are inappropriate to the time frame of military land-use. Second, a large diversity of species, ecosystems, and habitats are of ecological concern on DOD lands. Therefore, it is unlikely that only one or even just a few models will be adequate in considering how to manage these ecosystems, species, and habitats. Third, the intensity of military land use is high. Typical activities include tank maneuvers, ordnance activities, and testing of explosives. Fourth, the variation of land manager experience and skills across the 425 major installations is large. At some sites the land managers have considerable experience and tools available for their analysis. At other sites, vegetation maps of the installations do not exist, and there is little GIS expertise. Very few of the installations incorporate ecological information into their range decisions other than the preservation of threatened and endangered species. Therefore, in considering how to provide tools and support for military land-use decisions, one needs to address the variety of information and analysis tools that are available.

Grassy habitat required by the rare Henslow's sparrow.

The typical tools for ecosystem management include data, data manipulation tools, and models. The type of information may range from in situ data to remote-sensing data. Generally, remote-sensing data is broad ranging and provides uniform coverage across all sites but is less accurate than in situ data. However, remote-sensing data is currently updated more frequently than in situ data typically is. Data manipulation tools include geographic information systems (GISs), statistics, graphics, and maps. A working understanding of these tools is necessary in order to fully understand the data, the data gaps, and the accuracy of the models.

Ecological models are used to describe the environment, project the ramifications of alternative management scenarios, organize data, show gaps in information, and allow users to focus on temporal and spatial scales relevant to environmental management. These models are typically used to project future potential. However, they do have limitations; the projections simulate only one set of potential future conditions (Dale and Van Winkle 1998). Unfortunately, our current level of understanding of complex environmental systems, as reflected in a model, will rarely be adequate alone to provide simple answers to environmental questions. Nevertheless, model projections remain our best source of information for extrapolating limited theory and field and laboratory data to the real-world decision arena. Projections provide an understanding of the factors that will be important to future land conditions under certain management activities. Van Winkle and Dale (1998) point out the following needs:

- to understand models as part of a process that includes exploration and refinement and not only as final publication
- to make greater use of models to help improve ecological understanding
- to standardize terminology (e.g., calibration, verification, and validation)
- to minimize the gaps between claims, expectations, and the scientifically legitimate roles of models and the modeling process in policy and management.

The continuing challenge is to develop credible models whose purpose ranges from improving ecological understanding to providing useful information for decision making. It is this challenge that this SERDP project addresses.

This report describes the ecological models that were developed under SERDP project CS 758-62, Ecological Modeling in Support of Military Land-Use Decisions. First, the general approach is set forth, and then example models and their applications are described.

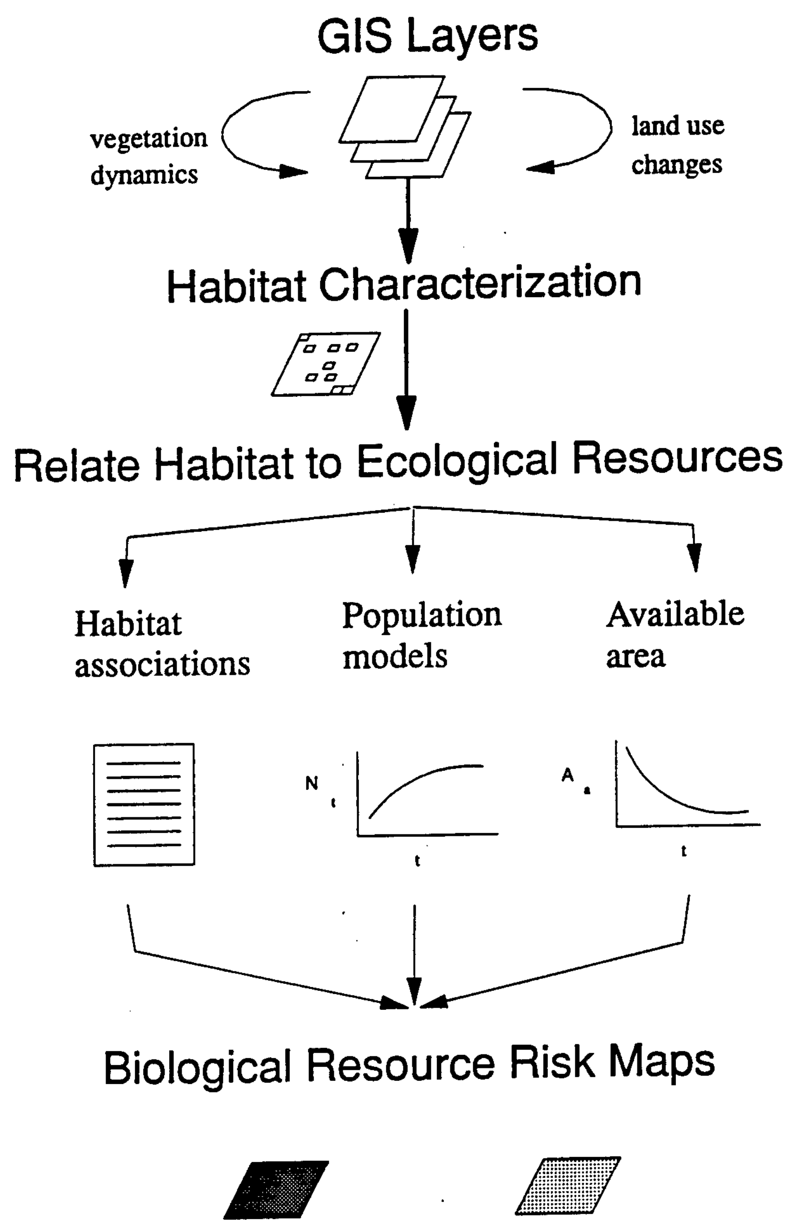
APPROACH: A SUITE OF ECOLOGICAL MODELS

The general approach of our project was to develop a suite of ecological models that together can predict where natural resources occur under various land management strategies and identify features that are at risk under particular land-use scenarios. The types of ecological models that are useful to DoD include habitat models, population models, metapopulation models, and landscape models. This approach recognizes that people obtain and use information in different ways. Therefore, information about these models and their results are provided in peer review literature, general reports that are available to land managers, and the web site **http://www.esd.ornl.gov/programs/serdp**.

Web Site Map

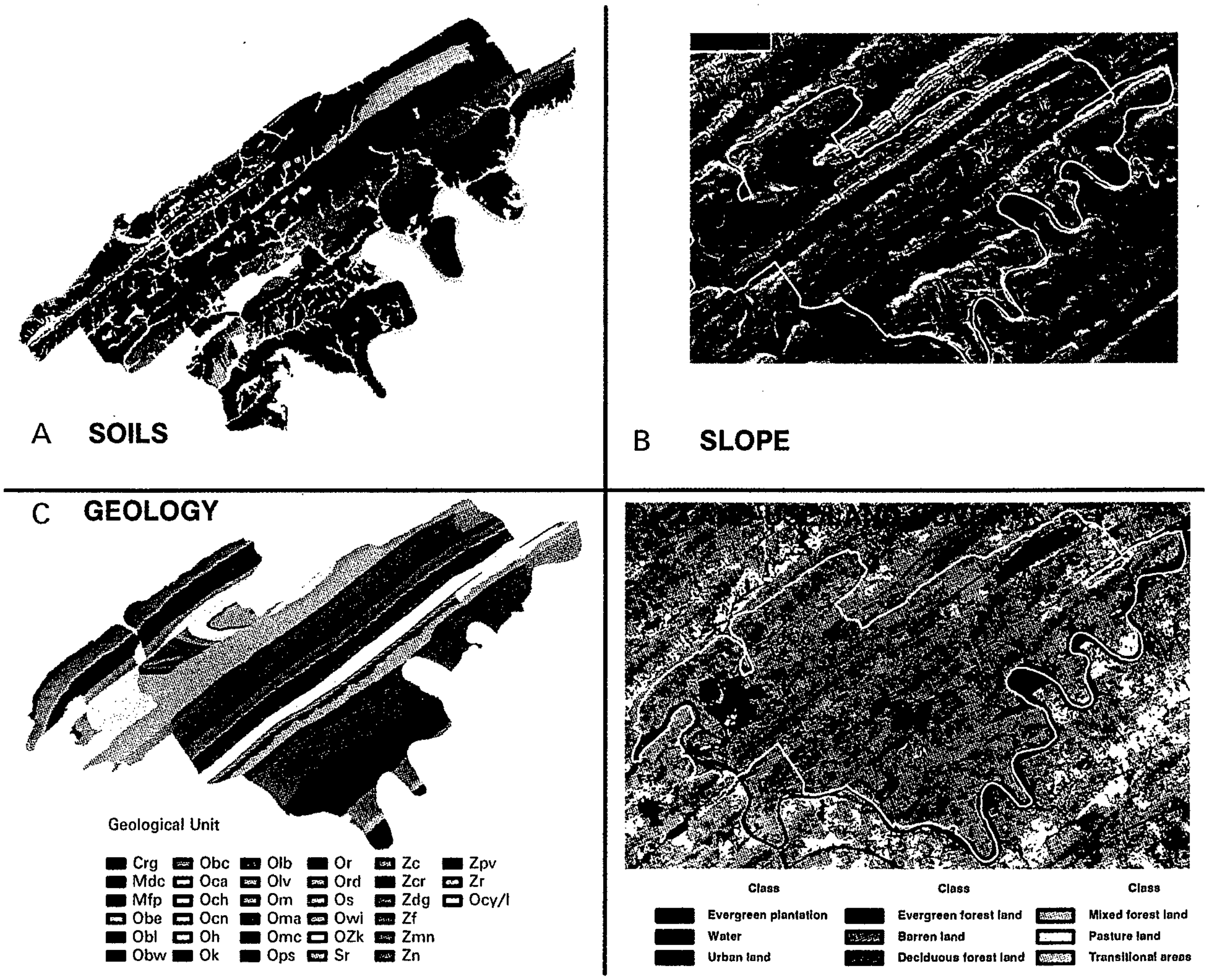
Home Page			
ORGANISMS AND HABITATS	***SITES***	***MODEL CATEGORIES***	***LAND MANAGEMENT ISSUES***
Henslow's sparrow	Fort Knox (Kentucky)	Landscape models	Managing natural resources on a single installation
Cerulean warbler	Fort McCoy (Wisconsin)	Metapopulation models	Managing natural resources across multiple installations
Red-cockaded woodpecker	Southeastern bases	Population models	Identifying critical habitat
Karner blue butterfly	Oak Ridge Reservation (Tennessee)	Habitat models	Predicting results of training and management actions
Henslow's sparrow habitat			Focusing monitoring activities
Cerulean warbler habitat			
Cedar barrens			

A strategy for assessing land-use impacts has been developed (Dale et al. 1997). Much information about changes that occur in natural resources is available in the form of spatially explicit data on environmental conditions and as output from models that simulate interactions between environmental condition resources and human activities. The strategy for assessing land-use impacts on natural resources developed in Dale et al. (1997) provides a framework for using relevant data and models to address questions of how management practices can promote both use and protection of resources, as shown in the diagram below.



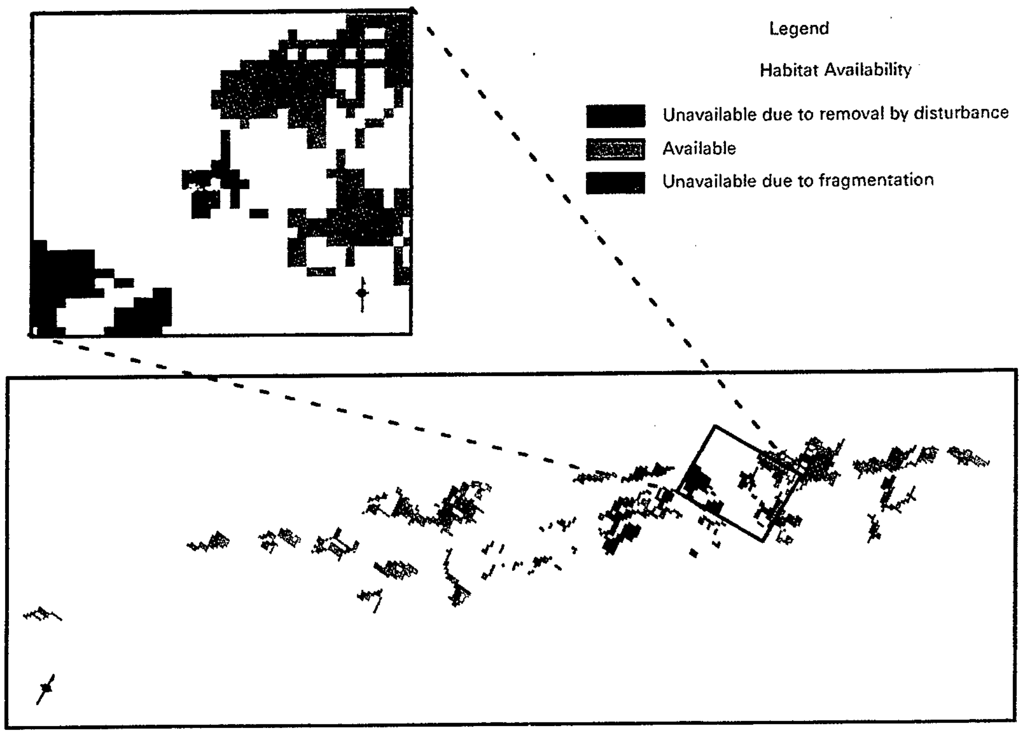
Strategy for assessing land-use impacts.

This assessment strategy integrates spatially explicit environmental data, using GISs with computer models that simulate changes in land cover in response to land-use impacts, as illustrated in map overlays.



GIS layers used to characterize the limestone barren habitat on the Oak Ridge Reservation (ORR). The soil series layer (A) and slope layer (B) are depicted as gray scales of the 122 different soil series and a slope range of 0% (white) to 182% (black), respectively, on the ORR (outlined in yellow). The geology layer (C) has 32 formations, 13 of which are Chickamauga limestone that support barrens (i.e., Ocy/l, Obe, Obl, Obw, Oca, Och, Ocn, Oh, Olb, Omc, Ops, Ord, and Owi) (Hatcher and others 1992). Layer D is the 1994 land use/land cover of the ORR (outlined in yellow), which was derived from classification of a Landsat TM image.

The computer models also simulate susceptibility of species to changes in habitat suitability and landscape patterns. The approach is applied to the management of limestone barrens on the Oak Ridge Reservation in eastern Tennessee. The models identify potential limestone barrens habitats by overlaying appropriate soils, geology, slope, and land-use/land-cover conditions. The validity of the model predictions is tested by comparing the results with information about known sites, that contain rare species in such habitats. The location of habitats at risk in the aftermath of human activities is also determined by using an available area model that identifies the size and proximity of sites that particular types of species can no longer use as habitat. The resulting risk map can be used in land management planning.



Map of areas of limestone barrens habitat predicted to be at risk both by direct (blue) and indirect (red) disturbance to 22-ha of habitat. The green sites are unimpacted limestone barren habitats.

The approach uses readily available in situ and remotely sensed data and is applicable to a wide range of locations and land-use scenarios. This approach can be refined on the basis of needs identified by land managers and the sensitivity of the results to the resolution of available resource information.

GIS-based habitat models provide a cost-effective means for locating areas likely to contain habitat of conservation concern, and for focusing monitoring in management activities at critical sites. Such models have been developed for Henslow sparrow and cerulean warbler, as well as limestone barren ecosystems. In addition, the GIS approach to identifying limestone barrens that was developed for the Oak Ridge Reservation was adapted for analysis of Fort Knox, as is described in the next section.

EXAMPLES OF MODELS THAT DEAL WITH LAND MANAGEMENT ISSUES

The Role of Soil Classification in GIS Modeling of Habitat Pattern at Fort Knox Military Reservation

INTRODUCTION: Management planning for the conservation of rare species on military reservations requires that maps of potential habitat distribution, but reliable information from ground surveys is not always available. GIS models often use vegetation land cover as ecosystem analogs, but the location of current vegetation does not always indicate the long-term or potential spatial pattern of habitats. In contrast to current land cover, soil diagnostic characteristics can indicate interactions with climate and land cover for hundreds or thousands of years and are the basis of the soil classification system used by the U.S. National Resources Conservation Service (NRCS) in county-level soil surveys. In Mann et al. (submitted), we evaluate a test application of a GIS model that relies heavily on soil characteristics to predict the spatial distribution of rare plant habitat.

BACKGROUND: The GIS model was developed for the Oak Ridge Reservation to predict the distribution of potential habitat for rare plant species that occur on limestone geology throughout the eastern United States. At least 19 plant species that are listed by either states or the federal government as threatened, endangered, or of special concern occur in threatened calcareous habitat (referred to as "TCH" in this report) that ranges from rocky or gravelly glades to cedar barrens and surrounding xeric woodland. Four rare species occur in suitable habitat at the Cedar Creek Slope Glades Preserve (referred to as the Preserve in this report) at the Fort Knox Military Reservation, Kentucky. The model was tested in the Preserve and then used the model to predict occurrences of potential suitable habitat on the rest of the reservation, including impact areas used for ordnance and tank training.

Cedar Barrens Habitat.

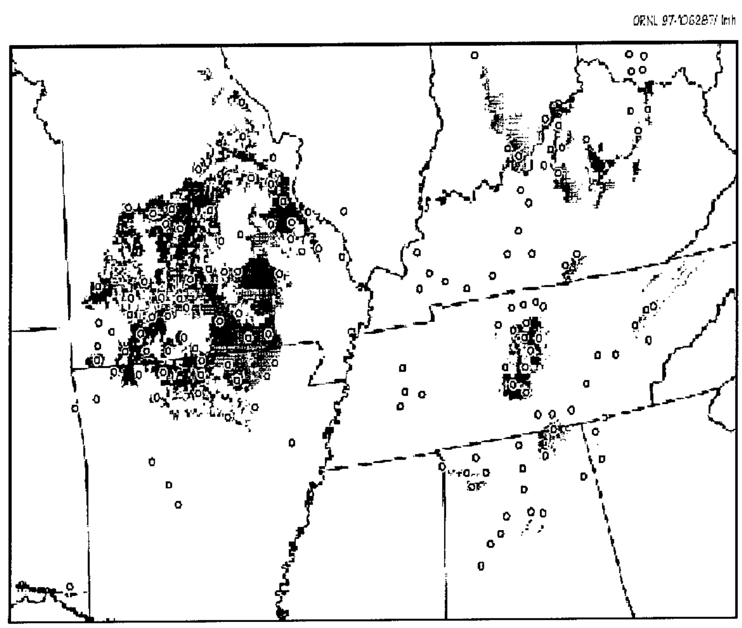
The Fort Knox Military Reservation occupies 44,150 ha in northeastern Kentucky. Most of the Fort Knox reservation has been surveyed for rare species except for the munitions testing area within the 21,000-ha ordnance impact area. The Preserve is a relatively intact 900-ha tract of TCH to the south. Potential TCH is known to be relatively extensive outside of the Preserve and has been impacted by military vehicle use, logging operations, grazing, and fire.

APPROACH: Our soil-based model assumes that soils of the threatened calcareous habitat have developed in response to similar spatial and temporal gradients of edaphic conditions and land-cover types. The soil component of the model uses the current U.S. soil classification and taxonomy. No theoretical basis had been found for predicting soil types of such habitats prior to our work (Dale et al. 1997). Based on diagnostic characteristics used in soil classification, we hypothesized that shallow, rocky soils classified as Mollisols are "core" areas of TCH with associated transitional areas of Alfisols. The presence of Mollisols indicates the long-term presence of herbaceous vegetation cover in both forest openings and part of the areas currently occupied by oak red-cedar woodlands.

At Fort Knox, the model predicted locations of TCH from positive intersections of data layers containing (1) soils classified as lithic Mollisols or Alfisols; (2) transitional, barren, urban, or grass land cover; (3) Salem or Harrodsburg limestone geology; and (4) slopes less than 25%. The application of the model was considered successful if the boundaries of TCH openings within the Preserve were contained within or coincident with a predicted patch.

The State Soil Geographic Database (STATSGO) and other USDA-NRCS data were used to predict the distribution of TCH at a regional scale. The map generated from the STATSGO analysis was evaluated by comparing it with the county-level distribution of known limestone-glade-endemic species. The success of the model was determined by a chi-square test of co-occurrence of (1) counties containing predicted calcareous habitat and (2) counties containing records of threatened and endangered or limestone-endemic species.

RESULTS: Our model accurately predicted all ten of the locations of the habitat patches that contain TCH within the Preserve at Fort Knox. Discussions with staff at Fort Knox indicated that the predicted potential habitat distribution was accurate, but the model may have over predicted potential habitat in the Impact Zone, where deeper soils are more extensive.



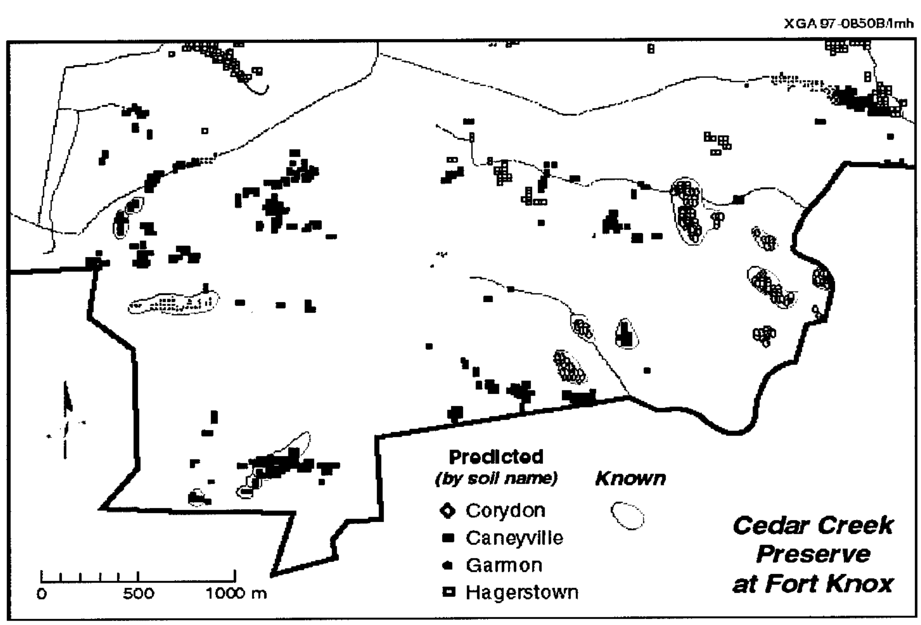
Distribution of predicted threatened calcareous habitat (TCH) Mollisol soils in the eastern United States and county occurrences of limestone glade endemics.

In the regional application of the model using STATSGO, TCH was predicted in 159 of 562 counties in the eastern United States, and 99 of 158 county occurrences of limestone/dolomite glade-endemic species from the literature were coincident with TCH. Thus, the coincidence of the model with the rare species survey was 63%; expected coincidence was 28% if the distribution of species were independent of predicted habitat within the study area ($\chi^2 = 91, p \leq 0.005$).

The Fort Knox and regional results imply that there is a fundamental similarity in soil genesis and classification in threatened calcareous habitats throughout the region. We found that the soil classification alone was not adequate to identify potentially suitable soil types: information about geology and rock fragments was also needed.

We concluded that current county soil survey data can provide data at a scale appropriate to the occurrence and distribution of TCH patches on the landscape. Using county soil survey data, we found that gaps between suitable habitat patches that would result from ordnance testing and tank training on military reservations would typically be greater than the grain size of the predicted habitat patches. The model predictions using STATSGO were coarser at 1-km^2 resolution than the distribution of TCH on the landscape and therefore would not be suitable for regional population models. Although the approach needs further testing in other ecosystems, the use of GIS models incorporating soil taxonomic information should become an increasingly viable approach for evaluating regional population dynamics and identifying degraded habitats suitable for restoration and management planning at Fort Knox and other military installations. In ecosystems in which edaphic constraints are less important than other factor (such as land-use history) additional data coverage would be needed to attain similar accuracy. Disturbance history, such as fire exclusion or grazing, often obscures patterns of historical habitat distribution. In such instances, and in areas of multiple private ownership with differing histories and uneven sampling of species and habitats, our approach may be particularly useful for conservation planning in partnerships between DoD and surrounding landowners.

Predicted and known rare plant habitat locations in the Cedar Creek Slope Glades Preserve at Fort Knox and the distribution of soils predicted by the model.



Henslow sparrow population model applied to Fort Knox, KY -- Managing natural resources on a single installation

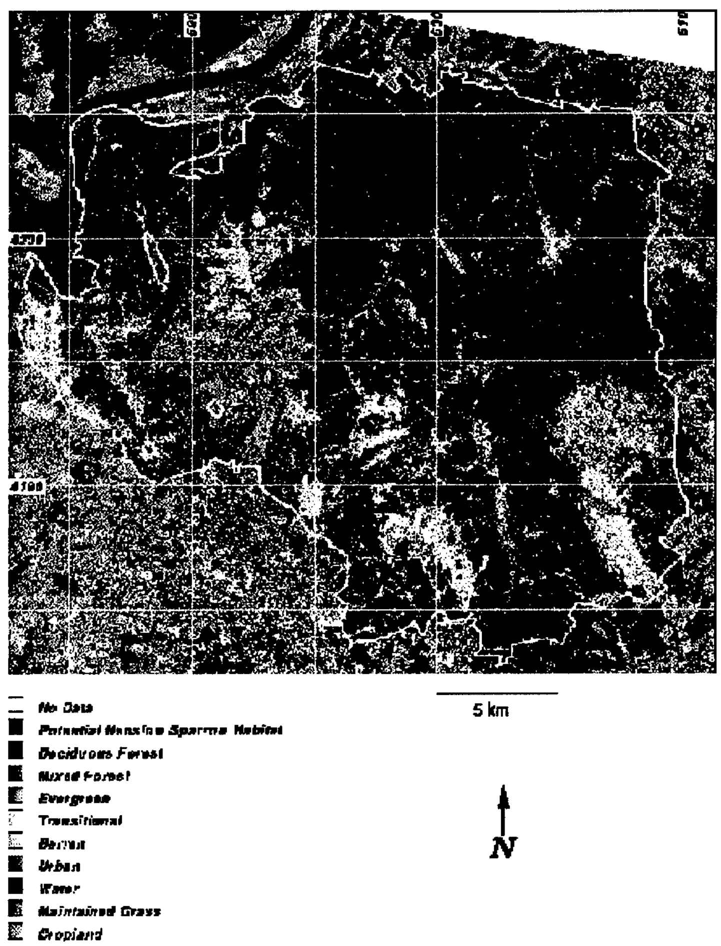
INTRODUCTION: Habitat loss and fragmentation have been implicated in the decline of many bird populations in North America and elsewhere. Deforestation and the conversion of native grasslands to pasture and cropland reduce the availability of suitable habitat. The increase in edge habitat that accompanies fragmentation may increase brood parasitism and nest predation and may lower the reproductive success of interior species. Isolation can interfere with dispersal and contribute to the decline of local populations. Fragmented landscapes may function as population sinks where reproduction fails to compensate for mortality. Persistence of a species in a sink landscape requires immigration of individuals from more productive source landscapes. Pulliam (1988) introduced the concept of demographic sources and sinks with reference to "habitat," or more generally "compartment," but the idea is easily extended to a heterogeneous landscape of multiple habitat types.

Cerulean warbler.

BACKGROUND: Training and testing on DoD managed land can lead to the kind of habitat fragmentation associated with the decline of bird populations. Neotropical migrants are a concern on some installations. For example, the golden-cheeked warbler (*Dendroica chrysoparia*) and black-capped vireo (*Vireo atricapillus*), both federally listed endangered species, are a conservation concern at Fort Hood, Texas. Elsewhere continental migrants are a concern. Henslow's sparrow (*Ammodramus henslowii*), for example, is a conservation concern at Fort Riley, Kansas, and at Fort Knox, Kentucky. Henslow's sparrow is listed by the Kentucky State Nature Preserves Commission as a species of Special Concern, and the largest documented summer population in Kentucky is found at Fort Knox, where grasslands in the vicinity of Godman Army Airfield are managed as a protected area for the species. Compliance with directives for ecosystem management and preservation of biodiversity on DoD lands requires assessment of how landscape pattern and changes in landscape pattern affect bird populations. Managers and planners of DoD installations need to know whether the landscapes they manage are sources or sinks for species of conservation concern and whether changes in land use or landscape pattern could shift a landscape from sink to source or vice versa.

APPROACH: We developed a model of how the spatial distribution of nesting habitat affects the reproductive success of territorial migrant bird species breeding in fragmented, patchy landscapes. The model combines a landscape perspective with demographic modeling to investigate how landscape pattern might impact the persistence of avian populations. Specifically, the model uses information on landscape structure to estimate b_x, the expected number of female fledglings produced by a female of age x. Designed as an assessment tool, the model strives for simplicity and ease of implementation. Accordingly, the model is primarily phenomenological and does not attempt a mechanistic description of avian biology. Model inputs and the data required to test the model are quantities that can be taken from existing literature or might reasonably be collected as part of a demographic study. The model was specifically developed for the assessment of avian demography on DoD installations, and we illustrate its application with an example of Henslow's sparrow at the Fort Knox Military Reservation, Fort Knox, Kentucky. The model was also been applied to Henslow's sparrow at Fort Riley, Kansas. The model's general structure applies, however, to other territorial migrants on other landscapes, both public and private, including other DoD installations.

In brief, nesting habitat is mapped with a regular grid of square cells. Neighboring cells are aggregated to form patches. Territories are distributed among patches by using incidence functions describing the relationship between species' occurrence and patch area. Nesting success in each patch is a function of the patch's edge to area ratio, reflecting the increased risk of nest predation and brood parasitism associated with increased edge. The number of female fledglings produced in all patches is used to calculate the expected number of female fledglings per female. This demographic variable, an explicit consequence of landscape structure, is combined with survivorship in a life-table model to calculate the demographic indices of net lifetime maternity and the finite rate of increase. These indices provide a simple characterization of the landscape as a population source or sink.

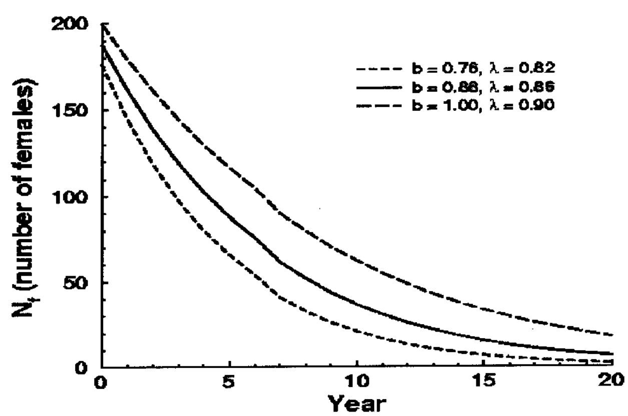


Predicted distribution of potential Henslow's sparrow nesting habitat at Fort Knox, Kentucky. The spatial resolution of the map is 20 m.

RESULTS: Our habitat model predicted 859.5 ha of potential Henslow's sparrow nesting habitat at Fort Knox. The model aggregated this area into 3335 distinct patches. However, only 21 (0.6%) of the patches were large enough to support nests. Most patches were either smaller than the territory size (88% of the patches were < 0.4 ha), or, because of the area sensitivity of Henslow's Sparrow, the patches were unlikely to be occupied. The largest patch was only 51.1 ha. Thus, only 201.4 ha of the potential habitat was utilized. The 21 occupied patches supported 100 nests and produced 449 ± 4 eggs, but only 39 ± 5% of the nests successfully fledged young, and only 39 ± 5% of the eggs were fledged. Three patches were responsible for approximately 80% of the fledgling production. Productivity was limited to 1.76 ± 0.21
fledglings per pair, and $50 ± 0.03% (72) of the fledglings were female. Rarely, a patch produced only male fledglings. With $b = 0.88 \pm 0.12$ female fledglings per female, the expected net lifetime production of females per female, R_0, is <1.0 (i.e., less than replacement), and the population's finite rate of increase [lambda] is <1.0. The landscape's production of females is insufficient to compensate for mortality reflected in juvenile and adult survivorship, and, in the absence of immigration and assuming constant demographic parameters, the population will decline. The model indicates that the Fort Knox landscape is a population sink for Henslow's sparrow, with an annual rate of decline of approximately 14%. Analysis of the model results suggest that Henslow's sparrow is declining at Fort Knox because of a combination of low reproductive success and low survivorship. Persistence of Henslow's sparrow at Fort Knox appears to require recruitment of individuals from other parts of the species' range. This may represent the historical situation at Fort Knox because the landscape is on the southern edge of the species' summer range and may have always represented "marginal" habitat.

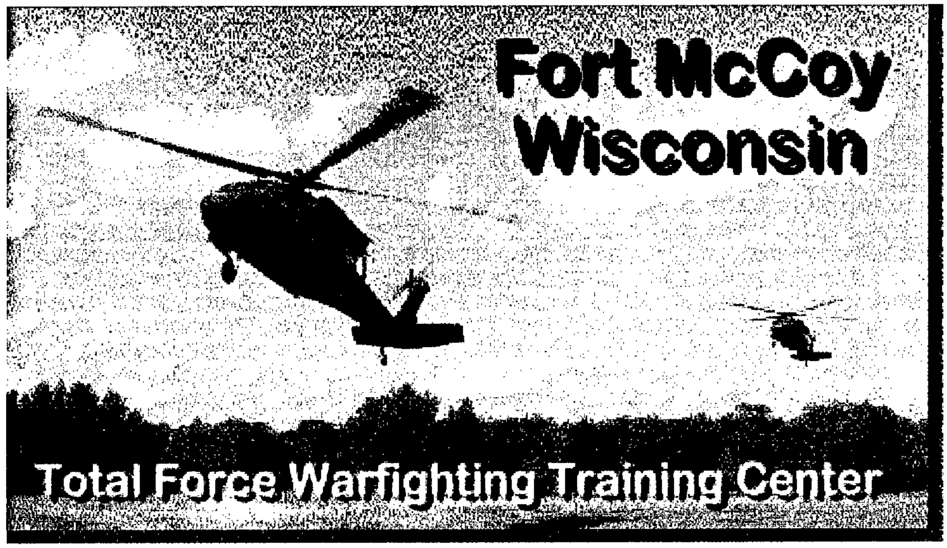
The model we have developed requires further testing at Fort Knox and elsewhere, but we have demonstrated that a simple combination of landscape and demographic modeling can yield a useful assessment tool. Although some components of the model need further refinement, the model's value is in large part a function of the habitat map and biological parameters used as model input. Quality habitat maps are required, and basic life-history data for species of conservation concern on DoD lands are vital. In the absence of such data, we are forced to extrapolate from other species in other regions that may be only weak ecological analogues. The required data can be difficult to obtain and may require long-term monitoring and field work, but they are crucial for accurate assessment of avian demographics and persistence in DoD managed landscapes.

Model projection of the Henslow's sparrow population at Fort Knox, Kentucky. The solid curve is the model projection for the mean. The broken curves bracket the mean by one standard deviation.



Spatially explicit models developed for Fort McCoy, Wisconsin

BACKGROUND. Fort McCoy is a 24,282-ha training area that was established in 1909 as an artillery training area and range. During May through October of every year, Fort McCoy is intensively used as a training site for both Active, Reserve, and National Guard soldiers of the Army, Navy, and Marine Corps.



Fort McCoy is also home to the endangered Karner blue butterfly (*Lyeacides melissa samuelis*). The larvae of the Karner blue are solely dependent upon its host plant, the wild lupine (*Lupinus perennis*). The wild lupine occurs widely distributed over the training lands of Fort McCoy. Since the Karner blue became federally listed as endangered in 1992, any military training on Fort McCoy is required by law to minimize their impact on both the butterfly and the lupine.

The modeling approaches that we developed address the issue of how the land managers can meet Fort McCoy's military training needs and yet still ensure that the environmental resources are protected.

1. Lupine habitat identification model --Identifying and locating critical habitats

INTRODUCTION: Managing natural areas for rare species or ecosystems usually involves managing habitat. Habitat management implies knowledge of the habitat requirements as well as information on the location of habitat patches.

Mapping habitat by means of traditional field methods can be expensive and time consuming, especially if areas are large or if habitat criteria require field measurements. Habitat models, however, can be used to focus field activities, thereby reducing field labor and cost. Habitat models also provide a basis for evaluating the effects of various land use strategies on the resource of concern.

One attribute of habitat not often included in predictive habitat models is soil characteristics. Soil characteristics and soil taxonomy may provide important clues to identify habitat suitability. We describe three case studies in which Soil Survey data have been used in GIS-based habitat models with varying degrees of success.

APPROACH: In the GIS-based habitat models, U.S. soil taxonomy is used to provide a conceptual

approach that incorporates long-term landscape-scale influences of soil forming processes on soil characteristics. By using our approach, we can eliminate soils that have not been historically associated with the species or ecosystem of interest.

Approach to develop GIS-based habitat model for natural resource of concern.

1. Set goal:
Determine resource of concern (e.g., species or ecosystem for which model will be produced).

2. Review literature and expert advice:
Determine the habitat requirements of the resource.

3. Develop initial hypothesis:
Develop a qualitative description or algebraic expression that relates potential map layers to the habitat criteria for the resource.

4. Build habitat map.
Acquire GIS data layers and combine as required by description or expression developed in step 3.

5. Test predictions:
Compare predictions to known habitat locations or acquire field data to test accuracy of predicted map from step 4.

6. Revise hypothesis:
Based on results of step 5, determine which aspect of the description or expression can be revised or added to improve predictions.

Karner Blue Butterfly Habitat Model.

Step 1. Set the goal. The Karner blue butterfly is a federally listed endangered species that occurs along the northern tier of states from Minnesota to New York. Karner blue butterfly (KBB) distribution coincides with the northern portion of the range of wild blue lupine the only species on which KBB larvae feed. KBB are abundant at Fort McCoy, in the west-central portion of Wisconsin. We developed a model for potential lupine habitat as a surrogate for KBB habitat.

Step 2. Review the literature. Lupine within the KBB range is found on sandy soil in post-Pleistocene terrain (Andow et al. 1994). The two primary soil characteristics are the sandy texture and relatively young age, with associated characteristics of cool-temperate climate and droughty moisture regime.

Step 3. Develop initial hypothesis; Step 4. Build habitat map. On the basis of literature review and discussions with KBB researchers, we determined that three soil series at Fort McCoy were suitable for lupine/KBB: Boone, Tarr, and Impact sands. Moderately well drained instances of these soils are less likely to support lupine. A habitat map including the excessively well drained phases of Boone, Impact, and Tarr sands was constructed from digitized soil survey data.

Step 5. Test predictions. Lupine and KBB surveys conducted in the mid-1990s were digitized into GIS layers, permitting comparison of the surveyed lupine locations to the soils survey results. In addition, evaluation of topographic factors suggested that west-facing slopes contain significantly more lupine than would be predicted by random distribution with respect to aspect.

Step 6. Revise hypothesis. The revised hypothesis divided Fort McCoy into three categories as shown in the map at the right:
(1) prime lupine/KBB habitat occurs on west-facing slopes where soils are Boone, Tarr, or Impact; (2) where these soil series occur on east facing slopes, habitat is suitable for lupine; (3) lupine does not occur on other soil types or in dense red pine plantations.

Predicted potential habitat for Karner blue butterfly (*Lycaeides melissa samuelis*) at Fort McCoy, Wisconsin

Migratory Birds

Step 1. Set goal. Henslow's sparrow (*Ammodramus henslowii*) and Cerulean warbler (*Dendroica cerulea*) are two migratory birds that are of conservation concern at Fort Knox in north-central Kentucky. Habitat models of both birds would permit effects of management actions to be evaluated.

Step 2. Review the literature. Nesting of Henslow's sparrow is associated with dense, tall grasslands that are not mowed or burned annually (Graber 1968, Zimmerman 1988). Historically, populations of Henslow's sparrow west of the Appalachians were probably primarily associated with native tall grass prairies, forest prairie mosaic, and moist grasslands in forest openings (Graber 1968, Zimmerman 1988).

Nesting habitat for cerulean warblers consists of extensive tracts of tall, mature, hardwood trees, and the species is known to nest from southern Ontario to the Gulf states, mainly west of the Allegheny Mountains and east of the Great Plains (Hamel 1992, Robbins et al. 1989, Bent 1953).

Step 3. Develop initial hypothesis; Step 4. Build habitat map. Prediction of Henslow's sparrow habitat at Fort Knox, Kentucky, was based on identifying sites that could support dense bunch grass vegetation typical of prairies. Soils identified as potentially suitable to support dense stands of grass were overlaid with a land cover map because only certain land covers (transitional, barren, or maintained grass) are consistent with Henslow's sparrow habitat.

The tall trees required by cerulean warblers would only be produced on soils with adequate depth and moisture. Only the deciduous forest classification was considered suitable for cerulean warbler habitat.

Step 5. Test predictions. Field testing was accomplished by sending two-person field teams equipped with portable global positioning system (GPS) receivers to ~140 randomly selected locations within Fort Knox. An error matrix was developed by comparing field observations to maps resulting from the habitat models. Both models were accurate at predicting non-habitat, but they underpredicted the presence of habitat. Underprediction was related to errors in the land cover input.

Step 6. Revise hypothesis. Attempts to reduce underprediction affected the overall accuracy of the models. A tradeoff between accuracy and underprediction is currently inescapable.

RESULTS: Edaphic controls on habitat can be inferred for most rare species and ecosystems, largely because vegetation plays a key role in defining habitat and because vegetation is often constrained by soil characteristics. Where the target organism has an obligate relationship with a narrowly defined vegetation regime that is itself constrained by edaphic factors (e.g., Karner blue butterfly in relation to lupine and sand), soils data should play a key role in the habitat model. As the organism's link with vegetation broadens from a single plant species to a wider vegetation category (e.g., Henslow's sparrow in relation to prairie grasses or Cerulean warbler in relation to old deciduous trees), the appropriate soil taxonomic level also increases, and the scale at which edaphic factors can be resolved becomes broader and the resolution of the model becomes coarser.

In order to use habitat models to constrain monitoring activities or to evaluate land use scenarios, underprediction of habitat needs to be avoided. Otherwise, monitoring activities might be eliminated from areas where habitat actually occurs, and the negative impacts of land uses might be greater than estimated. For this reason, the broadest approach must be taken when determining which soil types to incorporate into a habitat model. In general, soil taxonomy or soil characteristics should be used only to eliminate those soil taxa that are clearly unsuitable for the habitat of interest. A similar approach should be taken with non-edaphic criteria. However, this approach may reduce overall accuracy. Thus, model construction should be guided by the question being addressed.

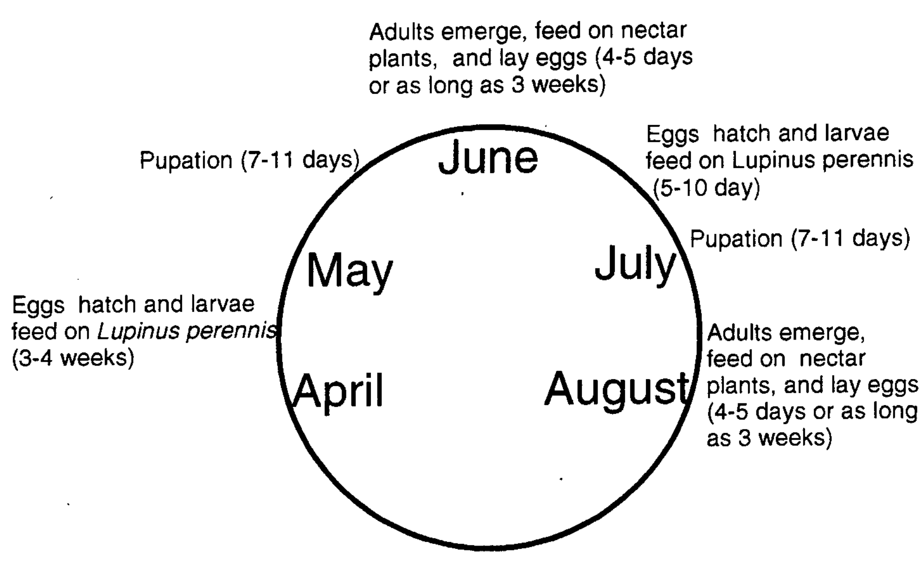
Even in locations predicted to be prime habitat, lupine and KBB occurred on only ~13% of the area. Models can predict *potential* habitat, that is, areas that meet criteria believed to encompass the organism's requirements. They cannot predict realized habitat, that is, locations where the organism actually exists. The realized habitat will be different from potential habitat for two reasons. First, there are errors and uncertainties in every model. Second, even a perfect habitat prediction will not likely match realized habitat because ecological factors such as competition, predation, fragmentation, or barriers prevent the organism from occupying or using the habitat. Thus, the appropriate way to test habitat models is not to monitor for presence of the target organism but to monitor for presence of the habitat.

2. Karner blue butterfly population model -- Managing natural resources on a single installation

INTRODUCTION: Regional population dynamics occurs in species that exist as a set of subpopulations distributed across space that interact with each other by means of dispersal and migration. The endangered Karner blue butterfly, *Lycaeides melissa samuelis*, is distributed patchily in open forests ranging from Vermont to Wisconsin. These patchily distributed and ephermeral habitats suggest that conservation actions for the species need to take into account the spatial arrangement of the butterfly and its habitat. Regional population models offer a means to organize the spatial information and to project spatial patterns of the subpopulations. Therefore, a regional population model was developed for Karner blue butterfly and applied to Fort McCoy, a military installation in west central Wisconsin, where the butterfly is locally abundant.

BACKGROUND: The Karner blue butterfly is bivoltine, and short-lived adults emerge in the spring and summer of each year. Eggs are laid on or near *Lupinus perennis* L. (wild lupine), on which the larvae obligately feed. The adults obtain flower nectar from several early successional species including the wild lupine. The maintenance of the Karner blue butterfly is, therefore, dependent on the existence of wild lupine habitat. Wild lupine typically occur in a shifting mosaic of patches within open meadows or woodlands that were maintained by wild fires, buffalo wallowing, or other disturbances. European settlers, however, initiated a series of disturbance. Today much of the wild lupine habitat has been lost due changes in disturbance regimes, natural succession, landscape fragmentation, and land use conversion (Clough 1992). Some estimate that the original oak savannahs in which the wild lupines occur once covered more than 12 million ha and now less than 2% of the area remains. In Wisconsin, the once 1.6 million ha of savanna are now reduced to 4,000 ha.

Life cycle of Karner blue butterfly.



Most of the studies concerned with the viability of the Karner blue butterfly have focused on the characteristics of the wild lupine habitat. While the maintenance of endangered species depends on conservation of critical habitats and ecosystems, there is also a need to determine how the butterfly demographics interact with features of the habitat.

APPROACH: On the basis of the limited data on the population characteristics of the Karner blue butterfly, we are developing a population model that allows us to answer questions about the sensitivity of the Karner blue butterfly to characteristics of the environment and the management actions. The model is currently parameterized for Karner blue butterfly populations at Fort McCoy, Wisconsin, where the butterfly populations are relatively large and stable. The model is designed not only to assess management actions that might alter the conservation of this threatened species but also to identify characteristics of the butterfly and their habitats for which improved information is needed.

The spatially explicit, stage-structured stochastic model for Karner blue butterfly is based on habitat suitability maps for Fort McCoy and on demographic data for the butterfly (e.g., distance adults disperse; number of individuals per unit area in the egg, larvae, and adult stage; and survival probabilities for each stage of the spring and summer broods).

RESULTS: The population spatial relationships are highly sensitive to the dispersal distance of the Karner blue butterfly. With the extremes of dispersal reported from field studies, very different patterns of population distribution result. Thus, the model results illustrate the necessity of including information about dispersal distances in order to understand the regional population characteristics of the Karner blue butterfly.

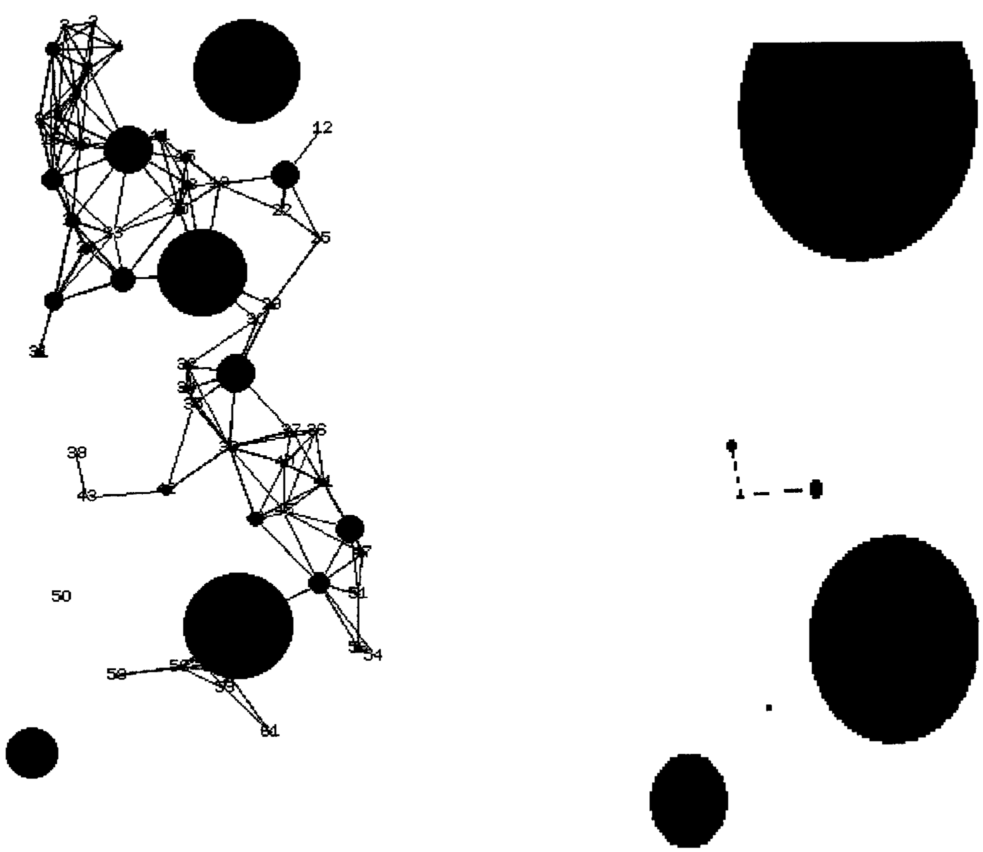
Nevertheless, there are similarities in model projections regardless of the inclusion of different dispersal distances of the butterfly. With largest dispersal distances, the projections indicate fewer patches, but some elements of the spatial configuration remain, such as the patch of wild lupine of the southwestern portion of Fort McCoy, which is a separate population under all scenarios. This pattern suggests the importance of developing a separate management plan for the southwestern population. The presence of a highway that separates that population from other patches of lupine further reinforces this need.

A second set of model simulation runs explored how changes in the characteristics of the

population affected the butterfly population structure. By *population structure*, we mean the number of individuals in the egg, larvae, and adult stages over time. The greatest fluctuations in the trajectory were due to changes in survivorship from the egg to larvae stage (G_1).

Analysis of the model results indicates that improvements are needed in estimates of the population parameters for adult dispersal and for survivorship from eggs to larvae in order to fully understand the effects of dispersal and survivorship on populations of the butterfly. Clearly these parameters are critical aspects of the butterfly biology. The model results also identify locations of subpopulations of the butterfly at Fort McCoy that require particular conservation focus. Thus the Karner blue butterfly model illustrates two benefits of using regional population models in efforts to enhance conservation: they can identify parameters for which uncertainties need to be reduced, and they can indicate features of the specific subpopulations that require management attention.

Maps of Karner blue butterfly populations from the population model. The population circles are proportional to their carrying capacities. The lines indicate migrations occur from one population to the other (expected number of migrants >0.1). The maps shows the spatial distribution of 61 (left) as compared to 7 (right) patches that result from assuming a butterfly dispersal distance of 400 m versus 1000-m, respectively.



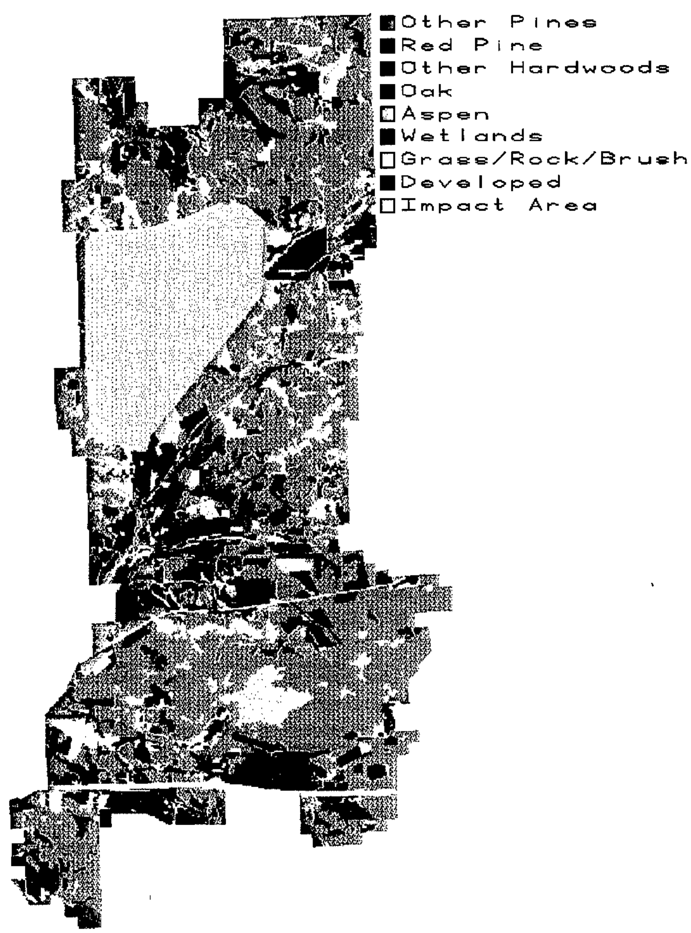
3. Transition matrix model — Predicting the results of land management actions

INTRODUCTION: Adaptive management is the current approach used to evaluate impacts to natural resources and to modify human actions as needed to protect those resources. Adaptive management emphasizes decision making as a continuing process rather than a discrete endpoint (Heifetz 1994). Adaptive management assumes an ongoing, iterative process that is adaptable to new information, to changing societal goals, and to changes in environmental conditions that may occur over a broad scale or over a long time. Thus, adaptive management provides a useful paradigm in which to consider land-use effects on natural resources.

Consideration of land-use activities leads to a focus on the ecology of the particular place (Beatley and Manning 1997). That is, one must consider both the constraints and opportunities that are provided by the environmental conditions of the particular locality. The ecology of a place not only can constrain the opportunities for development but also can influence the effects that a particular land use will have on the environment. Subsequent changes to natural resources can influence future land-use options. Thus feedbacks between land-use practices and environmental conditions are important to consider.

Land planning should also recognize the potential for disturbances to occur (Dale et al. in press). Disturbances are a normal, integral part of many ecosystems and landscapes. If the potential for disturbances is not considered, the long-term sustainability of the landscape will be inappropriately managed. For example, eliminating fires in forest areas of the western United States resulted in an abnormally high density of trees and a buildup of fuel. This, in turn, made the forest more susceptible to large-scale fires (e.g., the Yellowstone fires of 1988). An ecological perspective on land management therefore requires a realistic consideration of the frequency, intensity, and severity of disturbances that are specific to individual ecosystems.

Vegetation map of Fort McCoy.



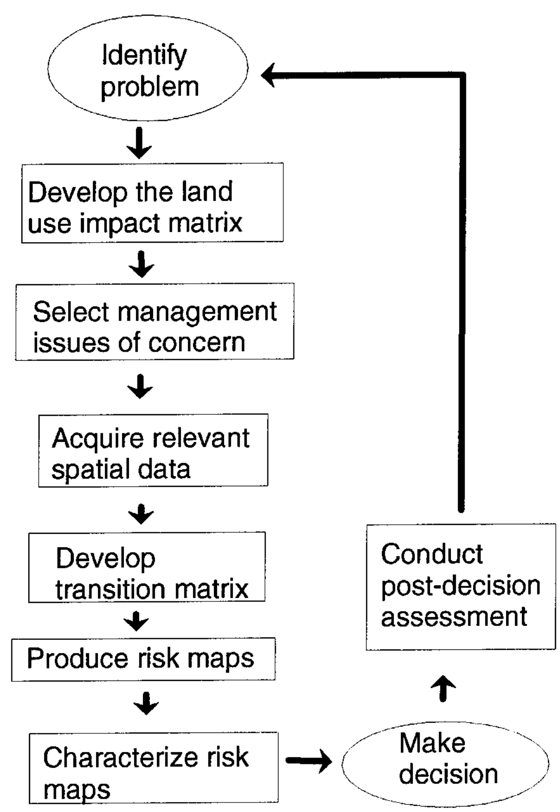
BACKGROUND: The field of landscape ecology deals with the spatial distribution of communities and ecosystems and the ecological processes that affect these spatial distributions. It is rapidly becoming the

applied field of ecology that is most useable and important to practicing land-use planners. This interest in landscape ecology has arisen at the same time that spatial data and tools to analyze those data have become available. Modeling tools have been developed as a way to relate such data to potential land-use decisions. Land-use models typically project land-use changes by using maps, and they consider spatial implications that may arise (e.g., edge effects or habitat fragmentation) and their implications for species or ecological systems. A tool that proves particularly useful in considering the effects of decisions on ecological properties is transition matrices. Landscape transition matrices, as mathematical models, offer a way to consider the ecological impacts of future land use activities.

APPROACH: Transition matrices are mathematical models that are able to simulate changes in the state of a given system. As related to landscape modeling, transition matrices simulate temporal and spatial changes in land use and land cover. A landscape transition model can be used to map and assess the impact of land-use activities on natural and cultural resources. Land-use activities can be characterized by using a common set of parameters (magnitude, frequency, areal extent, spatial distribution, and predictability) that can be applied either to specific activities or to different intensities of the same activity. This approach permits evaluation of the incremental and cumulative effects of diverse activities, such as road building, military maneuvers, grazing, timber harvests, or environmental restoration. Evaluating the risk posed to habitats and species can be expressed as the probability of a decline or enhancement in the abundance of guilds, species, or their habitat. Such an approach is generic, and with appropriate databases it can be applied to any site.

We formalized an approach to develop and apply landscape transition matrices to particular issues. This approach involves nine steps. **(1) Identifying the problem:** selecting the situation to which the approach will be applied determines the location, the issues of concern, and potential land-use activities and requires focusing on the species or ecosystem characteristics of concern and the land use activities that might occur. **(2) Developing a land-use impact matrix:** relating land-use activities to environmental characteristics such as species, ecosystem, or landscape characteristics. Unplanned disturbances such as introduction of non-native species or fires instigated by lightning should also be included when they pose management concerns (Dale et al. in press). **(3) Selecting management issues of concern:** prioritizing concerns according to the area most affected and intensity of effect on species, guilds or other natural resources. **(4) Acquiring relevant spatial data:** including linear features such as roads, rivers, or electrical transmission lines as well as polygonal

Approach for Using Transtion Matrix.

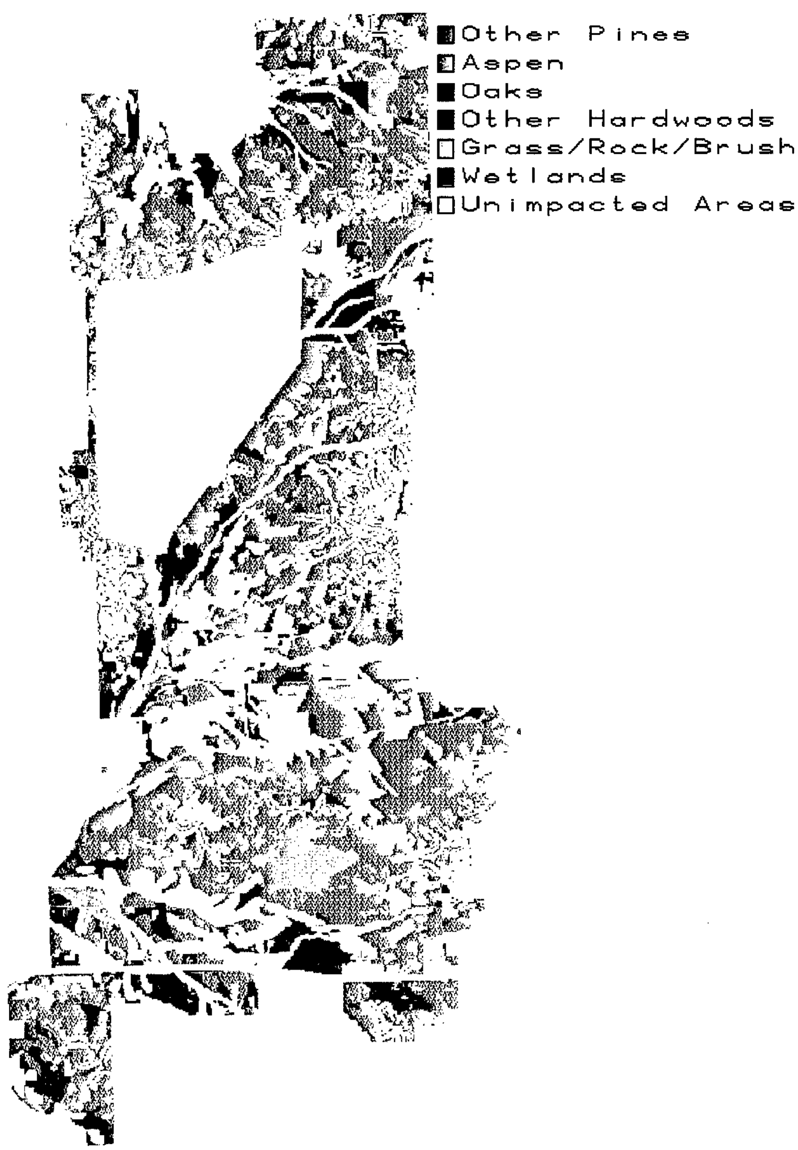


information on past land uses, soil type or texture, slope, aspect, and other factors which may influence how land uses may impact environmental conditions. **(5) Developing a transition matrix:** representing potential impacts of each activity on features of the landscape that are incorporated in the spatial data sets. **(6) Producing risk maps:** showing locations of habitats of natural resources at jeopardy under certain land management or land-use regimes.
(7) Characterizing risk maps: performing a spatial analysis of the features of the maps, using such metrics as edge density, contagion, mean nearest neighbor distance, mean proximity index, perimeter area fractal dimension, and mass fractal dimension. One way to interpret a risk map is to examine the landscape metrics before and after the proposed land-use activities. Alternatively, one can examine impacts of proposed land-use scenarios. **(8) Making the decision**: formulating a decision based on the ecological risk maps as well military, social, economic, and political goals for use of the land. **(9) Conducting post-decision assessment:** considering the ramifications of the decision and feeding them into future decisions that are made about the land.

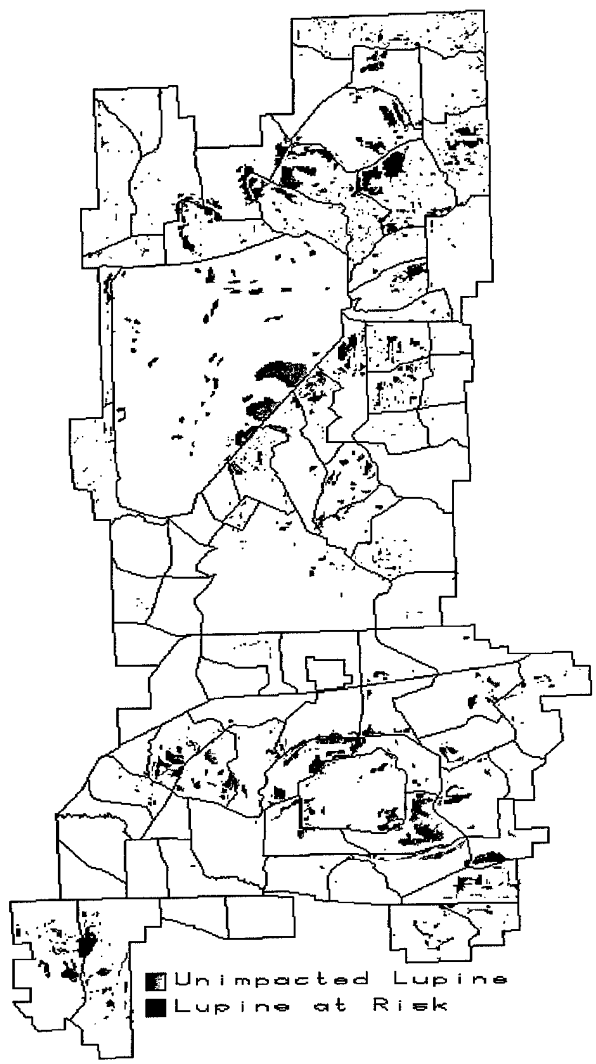
RESULTS: The approach was applied to two land uses at Fort McCoy: tracked and wheeled vehicle training in maneuver areas and prescribed burning. As an example, the ecological risk map for tracked and wheeled vehicle training (at right) shows that more than half of the area with pines, oak, and grass/rock/brush cover types at risk. These cover types are distributed throughout the Fort McCoy area.

The training impacts would increase the number of patches of these cover types and reduce the sizes of the largest patch and the average patch. In addition, there may be secondary impacts on the species that use these cover types as habitat. According to the lupine impact map (shown below) the risks that wheeled and tracked vehicle training poses to lupine are not uniformly spread across the installation. Overall, 56% of the lupine sites would be at risk. This amount of risk justifies an active management program for these lupine sites.

Ecological risk map for tracked and wheeled vehicle use.



Landscape transition matrices can be used to quantitatively characterize land-use activities, to develop a land-cover change risk model, and to develop a natural resource-susceptibility model. In addition to use in managing natural resources, the landscape approach is directly applicable to (1) planning for facility closures and realignment (e.g., identification of facility closures that provide the best conservation opportunities); (2) developing environmental restoration and waste management strategies; (3) supporting compliance with the Endangered Species Act, the National Historic Preservation Act, the National Environmental Policy Act, and the Executive Orders for Floodplains and Wetlands; and (4) developing integrated risk assessments that address cumulative effects.



4. Model of training impacts -- Predicting the results of training actions

INTRODUCTION: Researchers, biologists, and environmental contractors working for the U.S. Army have sought ways by which the military could become better stewards of the land upon which they train. Field inventories, environmental impact statements, and the development of management plans were some of the early environmental efforts that were undertaken on military installations. Recently, however, computer models have been applied to link ecological data into the military training decision-making process. Some of the current models include the Army Training and Testing Area Carrying Capacity ATTACC (Atomic Energy Commission 1998), Evaluation of Land Study (ELVS) (Siegel 1996), and Maneuver Area Damage Assessment Model (MADAM) (Sedlak and Brown 1992). All of these models seek to integrate ecological information with military training activities, but none of these computer models provide the range scheduler immediate information about the current ecological readiness of the land to receive military training.

We recommend an approach that provides the range scheduler an immediate visual display of the current readiness of the land to receive military training and of the projected land readiness based upon planned future training events. An indication of land readiness status (represented by the colors red, amber, or green [see table below]) would alert the range scheduler to assign a low priority to areas where training recently took place signified by red and amber and high priority to areas where training less recently took place (green). A land readiness status reflects the long-term goals of the natural resources staff in carrying out their mandate to integrate land management and military training activities. To illustrate the approach, we apply our model to the management of the Karner blue butterfly, an endangered butterfly that occurs on military land (Fort McCoy) in west-central Wisconsin.

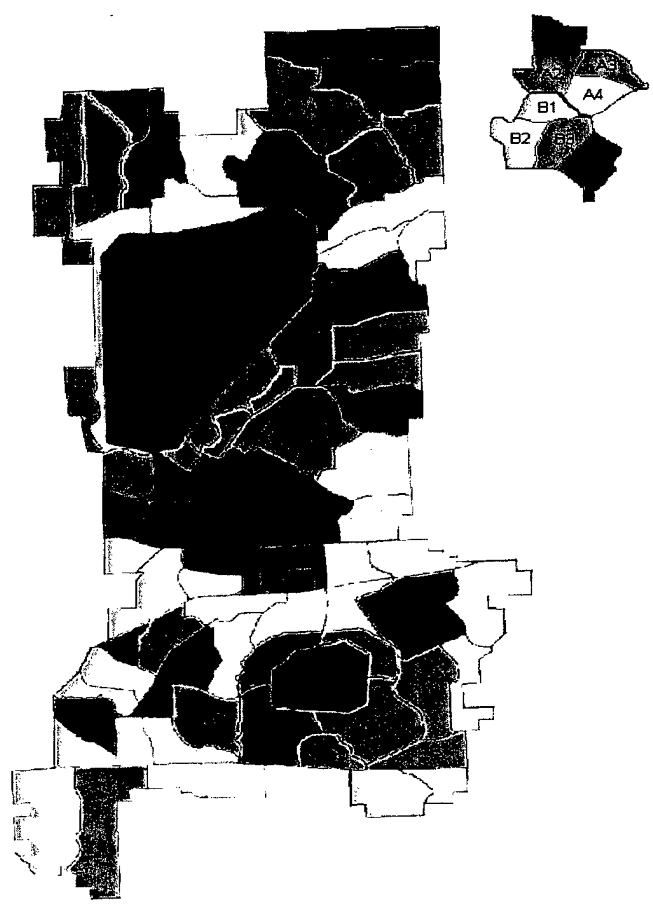
Colors of Training Area A and B are assigned as the color of the section that has not been trained on recently. This table represents the Training Year '98 use schedule at Fort McCoy based upon training assignments that were scheduled during previous years. Displayed are the section color codes and their respective color code for the training area.

Training							Date					
area	Oct-98	Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99
A												
B												
Training												
section	Oct-98	Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99
A1												
A2												
A3												
A4												
B1												
B2												
B3												
B4												
	Oct-98	Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99

BACKGROUND: Because lupine thrive in areas that receive periodic disturbance, some levels of training may be necessary to maintain suitable habitats for lupine. However, too much training may have a deleterious affect on lupine and Karner blue butterfly. We use the Karner blue butterfly, a species dependent upon Oak barrens ecosystems, as a surrogate to manage the barrens ecosystem, military training, and the required periods of disturbance.

APPROACH: The model was designed with Microsoft Excel, v 5.0, and programmed in Visual Basic (Microsoft 1992). The model is designed only for those areas defined as maneuver areas, within which off-road vehicle movement will occur. This model does not address or include impacts of training activities that occur on tank trails or improved road surfaces. The final goal of the model is to be linked with the Range Management Facility Scheduling System (RFMSS) (Construction Engineering Research Laboratories [CERL] 1989) to provide a visual display of land status to the range scheduler prior to the scheduling of training.

When the range scheduler receives a request from a military unit desiring to train on a section of Fort McCoy during a particular period, the scheduler would review the displays of the training areas and sections by a color scheme (black, red, amber, green). The color scheme is based upon the length of time that the training sections have been able to recover since their last disturbance and how long the lupine and Karner blue need before their habitat becomes unsuitable and in need of the next disturbance. Training is assigned based upon priority: dark green, green, or amber. Units are never assigned to sections coded black (cantonment area, impact area, and nature preserves that are permanently off-limits to training), and training is not recommended in sections colored red (indicating training within the last year; early successional species, lupine, and Karner blue butterfly flourish during this period). In amber-colored sections (where training occurred within the last 1–2 years), training is possible but not encouraged.



Training areas are color-coded to represent their priority for assignment for military training, in descending order: dark green, light green, amber, and red. In the inset, training areas A and B are divided into sections 1 through 4.

When training is assigned to amber areas, we recommend assigning low-to-moderate intensity wheeled vehicle training before assigning tracked vehicle training to a particular area. Habitat conditions in amber-colored sections still remain favorable for early successional species and the Karner blue butterfly. Green-colored sections are recommended for training (recovery time is 3 to 6 years following a disturbance) and tracked vehicle training has priority. In green-colored sections, the recovery status of the land meets land management goals (e.g., establishment of oak savanna), and habitat is starting to transition away from an oak barrens community and toward another community state. In dark green-colored sections, training is recommended because disturbance is past due and is currently necessary to reduce the more shrubby conditions to a successional state more representative of an oak barrens ecosystem (dark green is introduced as a new color for areas that have not been trained on for 7 or more years following disturbance). We recommend the assignment of high-intensity wheeled and tracked vehicle training to areas color-coded dark green.

The land use readiness of each section is simulated into the future, and the least disturbed section within each training area gives the training area its color code (Fig. 1 and Table 1). The current and proposed status of each section (red, amber, green) can be viewed daily or each time the update button is keyed.

RESULTS: Through our model we can provide answers to the following land management and range scheduler concerns:

- On which parcels of land can military training or land management activities be scheduled?
- How long should a parcel of land be rested between training events or land management activities?
- What tool can the range scheduler be given that would provide land readiness status information prior to the scheduling of training land assignments?

At Fort McCoy, the ecosystem management plan is to manage the oak barrens ecosystem, an area in need of disturbance. Our model can assist Fort McCoy biologists and range schedulers in their efforts to manage military training, the Karner blue butterfly, and the oak barrens ecosystem; in addition, it provides a framework for the development of other such models for use on other military lands. The ultimate goal of the model is to be linked with the Range Management Facility Scheduling System (RFMSS) (CERL 1989) to provide to the range scheduler a visual display of each section of land's potential to receive training prior to training being scheduled. This model is part of the Ph.D. dissertation of Mark Smith at the University of Wisconsin.

Red-cockaded woodpecker model for southeastern United States — Managing natural resources across installations

INTRODUCTION: The red-cockaded woodpecker (RCW; *Picoides borealis*) is a federally listed endangered species endemic to mature pine forests of the southeastern United States. Populations of RCW exist on many DoD installations across the Southeast, and their occurrence impacts the DoD training and testing mission.

BACKGROUND: The preferred pine-bunchgrass savannah habitat of the red-cockaded woodpecker was once widely distributed across the southeastern United States. However, fire management, deforestation, forestry practice, and other changes in land use have reduced and fragmented this once common and relatively contiguous ecosystem type. The distribution of longleaf pine (*Pinus palustris*) alone has been reduced from perhaps 37 million ha prior to European settlement to currently less than 1.2 million ha. Consequently, remaining populations of RCW are fragmented, small, and isolated, persisting primarily on federal and state properties and closely associated private lands. The U.S. Fish and Wildlife Service (USFWS) recovery plan for RCW calls for the establishment of at least 15 viable populations across the species' range. DoD lands figure prominently in the recovery plan; 6 of the 15 proposed recovery populations involve DoD installations. It is important to understand the role of DoD installations within the context of regional RCW recovery and management.

APPROACH: The fragmented and isolated occurrence of RCW populations is characteristic of a regional metapopulation, and regional metapopulation dynamics might allow for the persistence of the species despite the highly fragmented distribution of pine-bunchgrass habitat. It is not clear, however, that the 15+ populations of the USFWS meet all the criteria of a metapopulation. For example, because of the relatively recent history of RCW habitat fragmentation and insularization, an a priori assumption of a regional metapopulation is unwarranted. Therefore, we do not assume a metapopulation structure for the red-cockaded woodpecker. Rather, we ask a series of questions (1) Can the red-cockaded woodpecker be managed as a regional metapopulation? (2) Is the current distribution of red-cockaded woodpecker habitat consistent with long-term regional persistence? and (3) If not, what changes in habitat distribution or other management interventions would promote regional persistence? Similarly, we do not assume a metapopulation model but instead adopt a patch-based modeling approach from which metapopulation dynamics may or may not emerge. Our patch-based model takes the following form

$$dN_i/\mathrm{dt} = r_i N_i (1 - N_i/K_i) - D_i + C_i$$

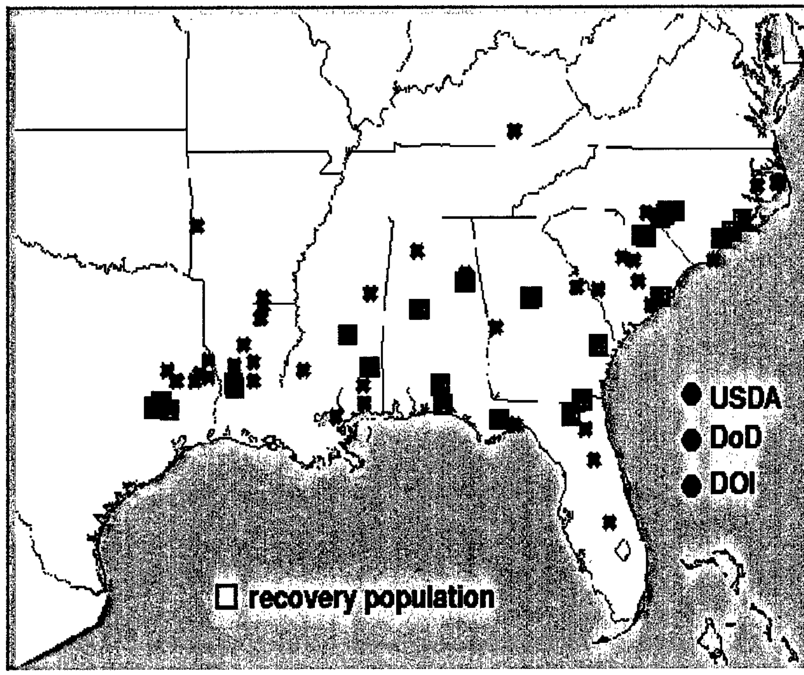
where

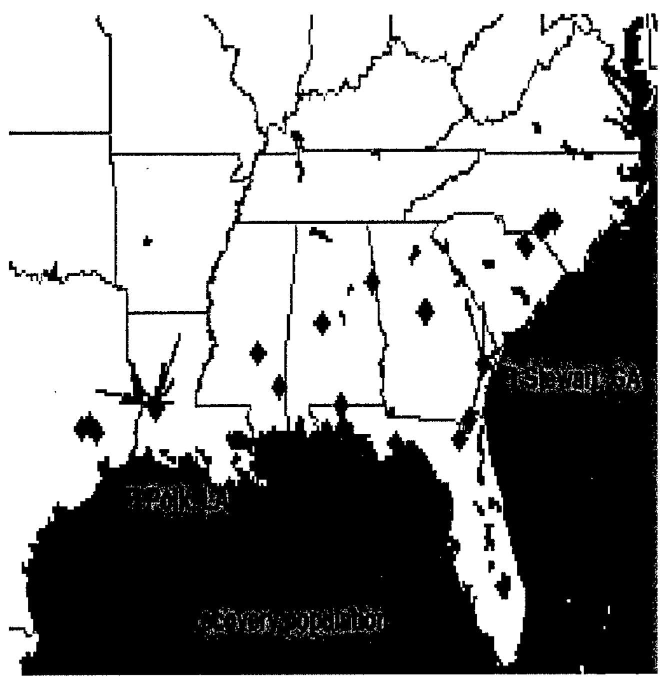
N_i = number of active RCW clusters in population i;
r_i = within-population rate of change in active clusters;
K_i = local carrying capacity (number of active clusters) of the population;
D_i = disturbance function specific to population i;
C_i = colonization of population i from other populations.

D_i is due to environmental stochasticity (e.g., hurricane damage) and $C_i = \sum_j c_{ij}$, where c_{ij}, the colonization of population i from population j is a function of the distance from population j and the number of active clusters in population j. Details of the model can be found in King et al. (in preparation).

We have parameterized this model with information currently available for red-cockaded woodpecker in the southeastern United States (e.g., distances between clusters). We also included the infrequent long-distance dispersal event that can connect otherwise disconnected populations in subtle but significant ways. We have examined records of long-distance dispersal for RCW across its range and used this information to calibrate the model's colonization function.

RESULTS: Mean within-population dispersal of RCW juveniles is on the order of 5–10 km.
Dispersal distances of up to 30 km are not uncommon, however, and dispersal by juveniles of 160 and 287

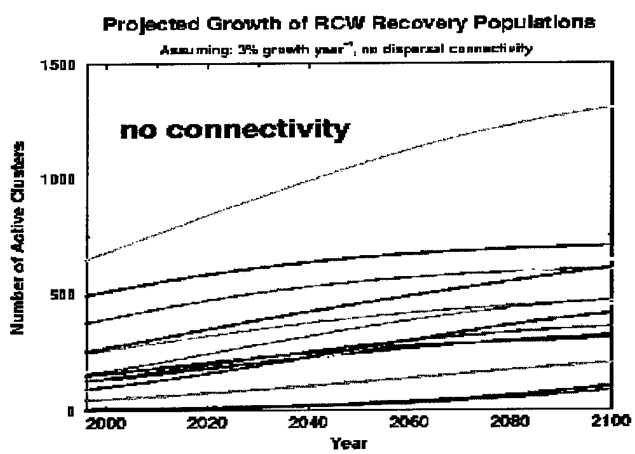


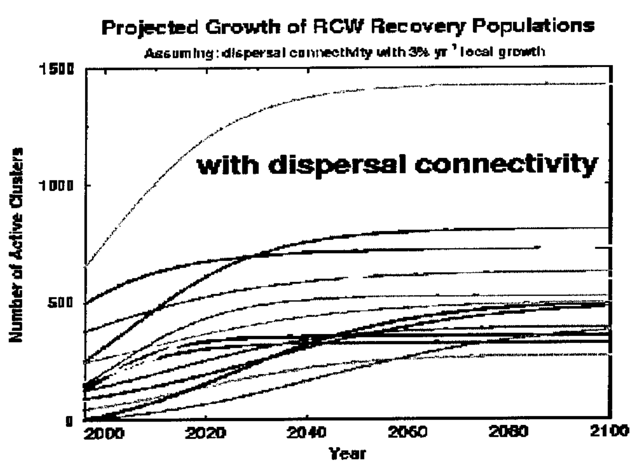


Federal RCW populations connected to Fort Polk and Fort Stewart at 200 km

km have been reported. We use these dispersal records to characterize connectivity among populations of RCW on federal lands of the southeastern United States. For example, the population at Fort Stewart, Georgia, is isolated from all other populations at dispersal distances of less than 100 km, it is connected to four populations at dispersal distances of 200 km, and it is connected to 12 populations at dispersal distances of 300 km. Similarly, the RCW population at Fort Benning, Georgia, is isolated from all other populations at dispersal distances up to 100 km, connected to four populations at dispersal distances of 200 km, and connected to 10 populations at dispersal distances of 300 km.

Long-distance dispersal connecting otherwise isolated populations can increase the potential of regional RCW recovery and persistence. In the figure below, we show results from the model applied to the 15 designated recovery populations without (top) connectivity by long-distance dispersal and with (bottom) connectivity by long-distance dispersal. Connectivity by means of long-distance dispersal and colonization increases the rate at which the modeled recovery populations reach their capacity for active RCW clusters.





Army's Vegetation Data from Sampling Points Are Extended Spatially Across a Military Base for Applying Spatial Vegetation Change Computer Models

INTRODUCTION: Simulating the changes in wildlife habitat as a result of military field training activities requires that we tell the computer how the vegetation across a landscape varies spatially at some starting time. The needs of particular wildlife of concern will determine what these vegetation characteristics should be included. The challenge is: the only available data are from transects recorded in the Army's Land Condition Trend Analysis (LCTA) databases. When viewed across the landscape, these transects provide only data for point locations. The problem is: How can the point data for vegetation characteristics be extended to estimate the spatial variability in a continuous way across the landscape of interest?

BACKGROUND: For a case study, the Army base at Fort Knox, Kentucky, was used. Here, two bird species are of conservation concern: the Cerulean warbler (*Dendroica cerulea*) and Henslow's sparrow (*Ammodramus henslowii*). A vegetation model was designed to screen computer-simulated vegetation characteristics over time and space. These characteristics indicate the area's suitability for providing habitat for each of these two species. The most comprehensive LCTA data for this installation pertained to summer 1991. However, for this vegetation model to be useable, we needed spatial data describing the initial vegetation conditions. The methods by which we acquired the information are highlighted below. Army training areas 18 and 14 were chosen as land areas to focus the application of the vegetation dynamics modeling. Area 18 is heavily forested and is therefore a likely area for cerulean warbler habitat. Area 14 has a significant amount of grass cover and is potentially suitable for Henslow's sparrow.

APPROACH: To extend the point-oriented LCTA vegetation data to spatial patterns, we applied statisical methods originally developed in the geosciences (Murray and Kickert, submitted). Rossi and others (1992) provide an introduction to geostatistical methods in ecology. Biondi and others (1994) give a comprehensive review of the literature for the application of geostatistics for environmental and ecological situations.

The variogram (Isaaks and Srivastava 1989; Rossi and others 1992) was the geostatistical tool used in this study to analyze the spatial continuity of the ecological variables. The experimental variogram plots the average squared difference between pairs of data points as a function of the average distance between the pairs. If a variable displays spatial continuity (i.e., if it is spatially autocorrelated), then the experimental variogram will tend to be low for nearby pairs of points and will increase in value as the average distance between the data pairs increases.

Numerical models are fit to the experimental variogram and used as parameters for geostatistical interpolation and simulation methods, including kriging, which are based on weighted linear combinations of the data.

Ordinary kriging was used when a variable exhibited spatial continuity; thus a variogram model could be fit to the experimental variogram. When spatial continuity could not be detected for a vegetation variable, then inverse distance interpolation was used. The estimation methods were applied over the northern and western portions of the Fort Knox site, where Training Areas 14 and 18 are located.

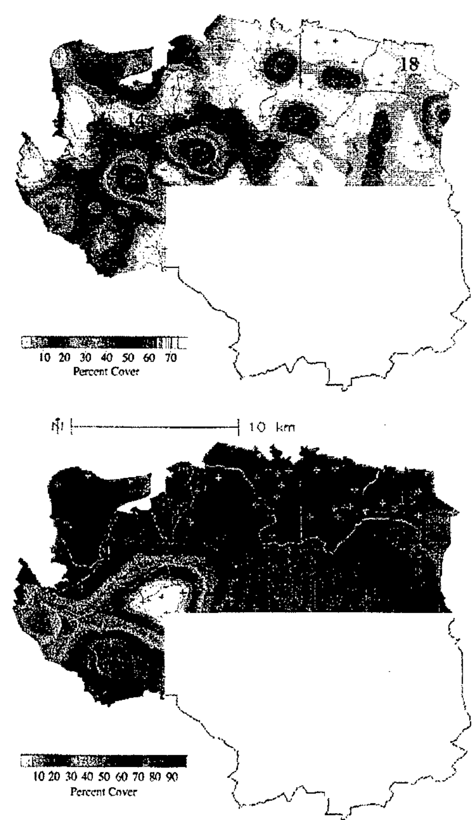
RESULTS: Twelve vegetation characteristics and bare soil amount were statistically analyzed on the basis of 139 LCTA plots around the Fort Knox installation. The amount of cover by annual grasses and annual forbs showed no detectable spatial continuity. This result is not surprizing in a deciduous forest landscape. The other 11 vegetation characteristics showed some level of spatial continuity.

For example, the kriged maps of perennial grass cover (potential habitat for Henslow's sparrow) and deciduous tree cover (potential habitat for the Cerulean warbler) show good continuity. The difference in spatial continuity between the two variables can be seen in the patchy distribution of perennial grass cover having a patchy distribution (A) in contrast with the broad swaths of land with similar amounts of deciduous tree cover (B).

The approach, using a variety of spatial statistics modeling techniques, can be applied wherever management has a need to know whether spatially continuous patterns exist but only point data are available. There is no guarantee that any given measured or observed entity will actually display spatially continuous patterns, but these approaches will illustrate the patterns. When other management models require spatial data as input, then this approach can be very useful.

A

B



Wildlife Habitat and Soil Erodibility Changes from Military Field Training: Tools for Computer-Based Spatial Projections

INTRODUCTION: Army troop readiness requires realistic landscapes in field training maneuvers. However, such maneuvers disturb the vegetation and soil. These disturbances reduce the desired realism and also jeopardize legally protected wildlife species by changing their habitats. To plan training maneuvers at a military base, it is useful to have a computer simulation model that describes the training-induced change in vegetation, and consequently in wildlife habitat, as well as changes in vegetative protection against soil erosion. Our objective was to develop a spatially explicit vegetation dynamics model useful for land management, for computer simulation of changes in wildlife habitat, especially with regard to species of concern, and for the vegetation factor in soil erosion.

BACKGROUND: As a test case for development, the model is based on the landscape and hypothetical training conditions at Fort Knox, Kentucky. Two army training areas, Areas 18 and 14, were chosen as the focus for the application of this model. Area 18 is heavily forested and, therefore, is a likely area for cerulean warbler habitat. Area 14 has a significant amount of grass cover and is potentially suitable for Henslow's sparrow.

APPROACH: The model includes sets of hierarchical screening equations of an "IF...THEN" nature for describing the suitability of vegetation characteristics with respect to the reported requirements of the wildlife of interest. The model is also equipped for simulating changes in the vegetative cover factor affecting soil erosion. The factor is based on Wischmeier & Smith (1978) for nonforested lands and on Dissmeyer & Foster (1984) for forests. To simulate changes in vegetation that would drive these responses, we initially searched the literature on ecological models for vegetation dynamics. Virtually all of the exitisting models are based on carbon and/or biomass dynamics (i.e., g/m^2), but this paradigm is not useful for describing changes in wildlife habitats. The only model that was based on changes in relative cover of different plant life forms is the model by Westervelt and others (1995). Even with that model, however, changes in vegetation height over time (and space) are not included. Such structural characteristics of vegetation are important when describing vegetation as habitat for terrestrial wildlife. We used the vegetation portion and soil moisture dynamics part of the Westervelt model, added a simple non-linear S-curve logistic model containing a parameter for maximum expectable height of a given plant life form, and rewrote the models in FORTRAN.

The model is programmed as a set of equations that keep track of increases in plant cover resulting from growth and decreases in plant cover because of the duration (hours) of various kinds of military field training activities, fire, and natural mortality. The model operates at a weekly time step for a landscape divided into contiguous square cells measuring 25 meters on a side.

The *non-spatial* data constants that are needed to use the model include the following: average monthly air temperature; average monthly total precipitation; base station elevation; and for each plant life form type, the average weekly temperatures and soil moisture amount below which growth does not occur and the values above which growth does not occur.

The *spatial data* needed for starting the model include the following, for each 25 times 25 meter square land unit cell: the initial beginning percentage of cover and initial height of annual grass, annual forbs, perennial grass, perennial forbs, shrubs, deciduous trees, and coniferous trees. In addition, spatial data constants are needed for ground elevation, soil permeability, soil water holding capacity, and soil organic matter percentage. Because such data are most likely available only as point data, we have used the procedures of spatial statistics as described in Murray & Kickert (1998) to obtain spatial data sets.

For describing military training land use at different times and in various locations, we used the variables of Westervelt and others: that is, the number of hours per simulation time step (week) for each land cell was occupied by each encampment, dismounted troops, untracked vehicles, and tracked vehicles (e.g., tanks). We needed either to obtain training records for these events at the specific installation or to postulate possible patterns when records were not readily available. Other investigators have used MIMs, Maneuver Impact Miles, but we found these useful only for evaluating physical soil erosion, not for evaluating vegetation and/or wildlife ecological impacts. It was also necessary to specify during which weeks and at which land-cell locations fires occurred. A fire impact index eliminates some vegetation, while triggering a delayed regeneration weeks later in others.

RESULTS: This vegetation model, with outout for wildlife habitat suitability and the cover factor for soil erosion, has been run successfully for a year-long simulation, and it is expected to be able to run for several simulated years. An example simulation was run starting in the first week of August, until connectivity by long-distance dispersal at selected locations during the third week of August, until the first week of June of the next year. Spring and summer is the time during which the Cerulean warbler and Henslow's sparrow, as migrants, could be present at Fort Knox. At training Area 18, model results showed that 39.2% and 32.4% of habitat was potentially suitable for the cerulean warbler (red) and 60.8% and 67.6 % was unsuitable (green) before and after training, respectively. At training Area 14 (not shown), results showed that 2.4 and 2.5% of habitat was potentially suitable for Henslow's sparrow and 97.6 and 97.5% was unsuitable before and after training, respectively; the results thus indicated little change. This does not account for the amount of aggregated suitable habitat that both bird species are reported to require. In both cases, the minimum areas would be sizeable proportions of either of these training areas. In training Area 14, a simulated change in the effect of the vegetational cover factor on soil erodibility was obvious but appeared to be largely a result of season rather than military field training.

This model has been adopted with modification to determine the best course of protection of sage grouse in the sagebrush-grasslands at the Yakima Training Center in Washington State. At that site, the model is focused on the impacts that tracked vehicles have on the vegetation characteristics that define sage grouse habitat and the changes of the characteristics over time at various locations. This work is also being considered for use and further application in the Defense Threat Reduction Agency and in the State Department. Provided that the required initial spatial data can be obtained for the vegetation characteristics, this tool can be adapted to other wildlife habitat conservation concerns.

We are not satisfied with the use of "number of hours" for various military training activities as the measures against which to project ecological responses. This is especially so, given the data in Jones and Bagley (1998) concerning the effects of tracked vehicles on vegetation in the shrub-steppe landscape at the Yakima Training Center in Washington State. We are exploring the development of a random walk simulation, which would be constrained by likely straightline-distance mobile behavior of tracked vehicles, terrain slope, and distance from commuter road to off-road training location. In this way, we expect to better represent the area within any land cell that is directly impacted by single passes, double-passes, four-passes, and eight-passes from tracked vehicles, and the subsequent decimation of relative vegetative cover and vegetation height. Not having access to field training records for Army maneuvers and any fires that result remains a major handicap. Without such data, any attempts to simulate ecological effects will remain hypothetical and theoretical.

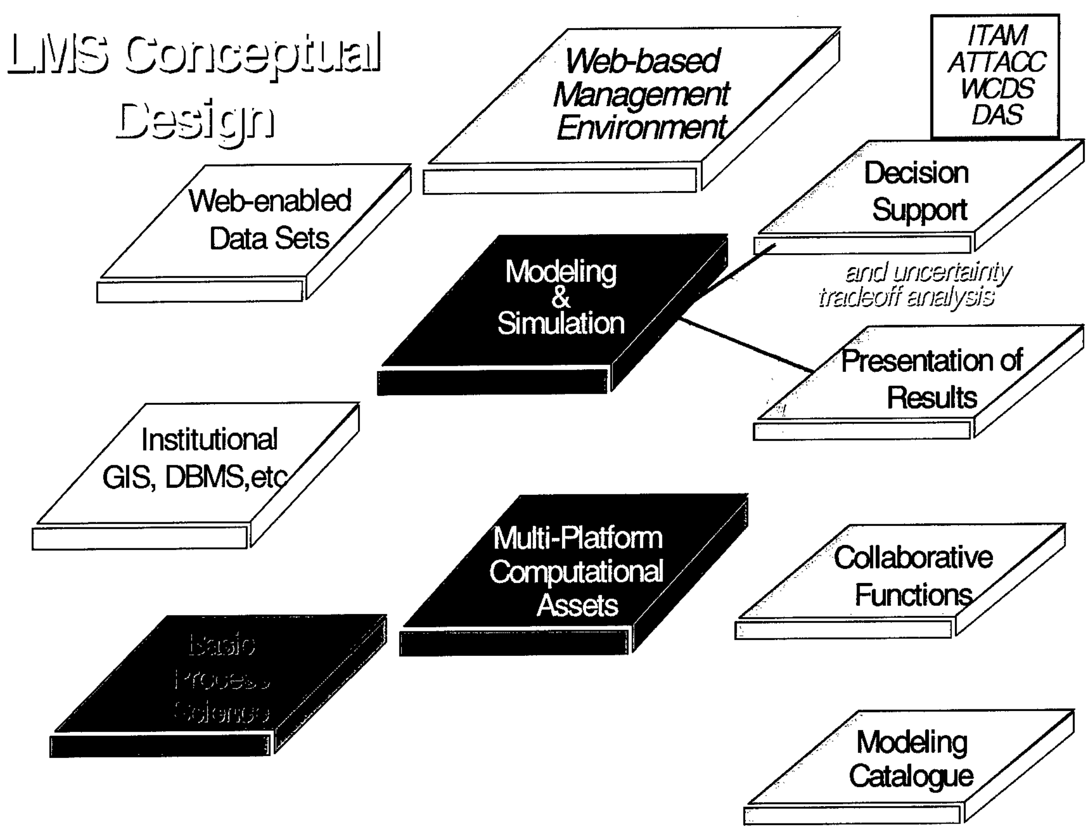
PROJECT CONCLUSIONS

To be useful for preserving the natural diversity and habitat on military insulations, each of the ecological models is designed

- to use information that is available to most installations,
- to be adapted to other similar concerns, and
- to have products that reflect the concerns of land managers.

These are the characteristics that make models generally applicable to both site-specific and regional decisions. Such models are useful to military land managers as well as other private and public land managers.

The insights from these models are meant to be incorporated into decision-making processes that involve mission needs and socioeconomic conditions. Decisions models include explicit needs for data and output from ecological models (such as the Land Management System [LMS]) shown below. In that diagram, the ecological models fit into the red box labeled "Modeling and Simulation." The output from the simulation model feeds into the "Decision Support" and "Presentation of Results" boxes.



The benefits from these ecological models are fourfold. A method to identify locations of habitat and to characterize key attributes of species at risk has been set forth. A framework to analyze potential impacts of land-use activities on natural resources has been developed. Case studies demonstrate these approaches at locations at Fort Stewart, Fort Riley, Fort McCoy, and the southeastern military installations. Finally, an approach has been developed that links management questions with models.

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